U. S. ARMY
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FORT EUSTIS, VIRGINIA

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VTOL DOWNWASH IMPINGEMENT STUDY
SURFACE EROSION TESTS

Project 9R38-01-017-29

Contract DA 44-177-TC-655

October 1960

prepared by :

HILLER AIRCRAFT CORPORATION
Palo Alto, California

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Hiller Engineering Report No. 60-84

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Palo Alto, California

for
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FORT EUSTIS, VIRGINIA

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FOREWORD

Hiller Aircraft Corporation was awarded Contract DA 44-177-TC-655 in April 1960 to extend the work performed under Contract DA 44-177-TC-500. This work was to include studies, tests and evaluation of the effects of downwash and slipstream forces of VTOL aircraft with respect to aircraft, supporting equipment, personnel and landing areas.

This report covers a portion of that work consisting of tests conducted over sites provided by the U. S. Army Engineers Waterways Experiment Station, Vicksburg, Mississippi. In addition to these test sites and general support of the test program, Waterways Experiment Station also provided the wave rods and recorder equipment used in the water tests and the classification and condition of the materials at the time of testing.

Work yet to be done under this contract consists of tests over the same or similar test sites with duct adapters simulating, plenum chamber and annular nozzle configuration ground effect machines, and side by side nozzles for VTOL aircraft. This work will be covered by a separate report. A summary report and edited film analysing the results of this contract and Contract DA 44-177-TC-500 will also be prepared.

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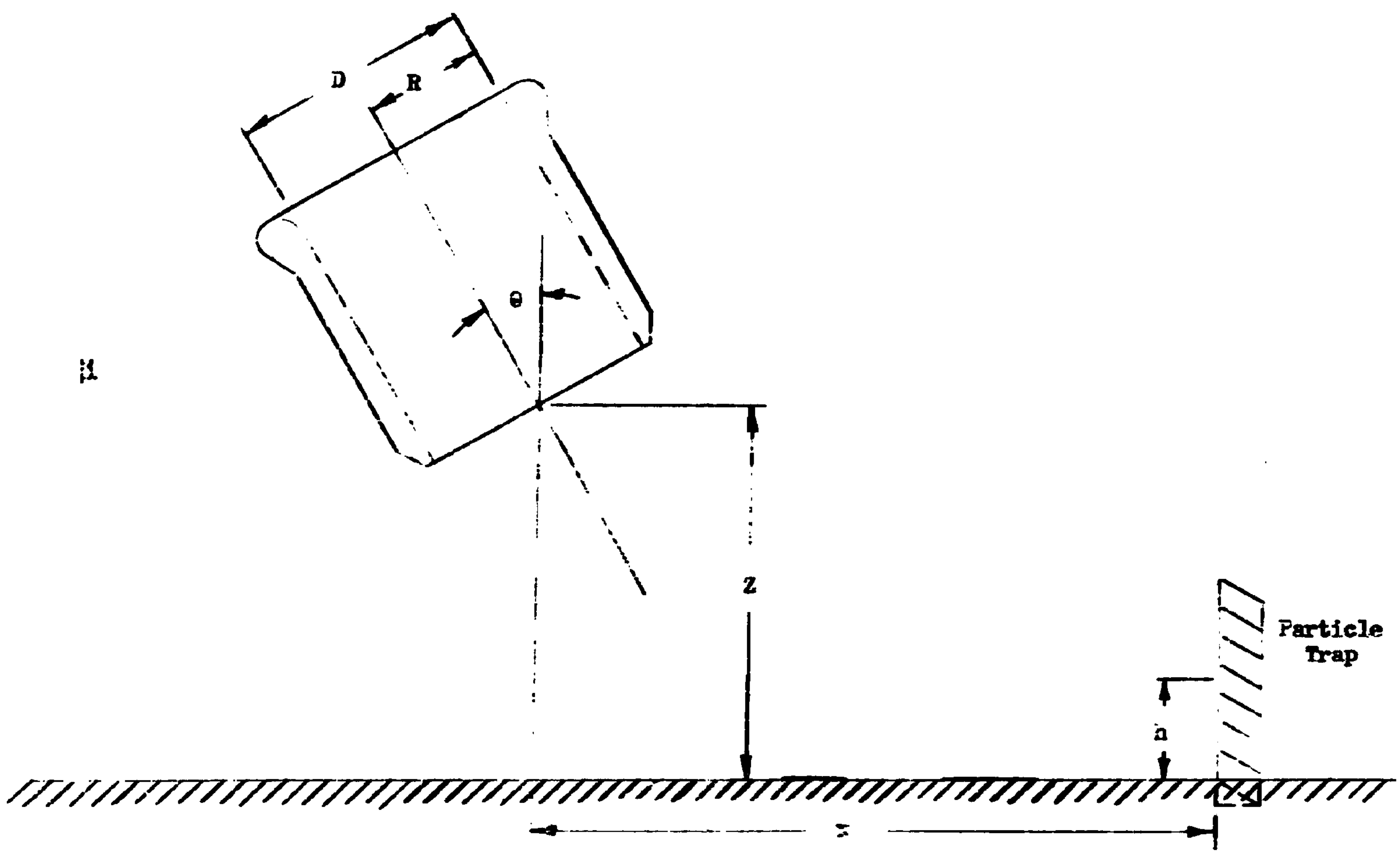
LIST OF SYMBOLS

a	Wave amplitude	ft.
D	Duct exit diameter (2.0 ft.)	ft.
D_H	Diameter of surface depression	ft.
f	Wave frequency	c.p.s.
h	Height of point under investigation above normal surface	ft.
R	Duct exit radius	ft.
V.L.	Volume loading (particle volume/maximum projected area)	inches
w	Disk loading (thrust/2.79)	pounds per square foot
x	Distance measured along the surface from a point directly beneath the duct exit to the point under investigation	ft.
Z	Height of the duct exit above the surface a Measured distance between exit and surface prior to run for smooth soil b Measured distance above mean water level prior to run c Distance between duct exit and bottom of furrow prior to test	ft.
θ	Thrust axis inclination	degrees
ϕ	Azimuth measured in the surface plane in a clockwise direction from the propeller axis projection or from a direction along the plowed furrows	degrees

SCHEMATIC DIAGRAM INDICATING DESIGNATION OF SYMBOLS

2.0 FOOT DIAMETER DUCTED PROPELLER



NOMENCLATURE USED FOR SOIL CONDITION

	Test Numbers
I Lean Clay (CL)	
A. Bladed Section	1 to 5 inclusive
B. Plowed Section (Flat)	6 to 30 inclusive
C. Plowed Section (Furrowed)	31 to 39 inclusive
D. Grassy Area (Unmowed)	64 to 73 inclusive
E. Grassy Area (Freshly Mowed)	53 and 54
	74 to 88 inclusive
II Fat Clay (CH)	
A. Weathered	89 to 92 inclusive
B. Bladed	93
III Sand (SP)	
A. Dry	44 and 45
	94 to 104 inclusive
	106 to 120 inclusive
B. Wet	42 and 43
IV Sandy Gravel (GW)	
A. As Deposited	40 and 41
	55 to 63 inclusive
	121 to 126 inclusive
B. Sprinkled and Compacted	127 to 137 inclusive
V Water	
A. Fresh	46 to 52 inclusive

This system of soil condition nomenclature was used to provide a complete cross reference between this report and Appendix I. A single designation was used which consists of:

1) A Roman numeral that designates the type of soil.
2) An alphabetical symbol that designates the soil preparation.
3) The test number assigned at the time the test was conducted.

A designation can consist of the first two parts when reference is made to a series of tests.

Example: Data designated I-B25.

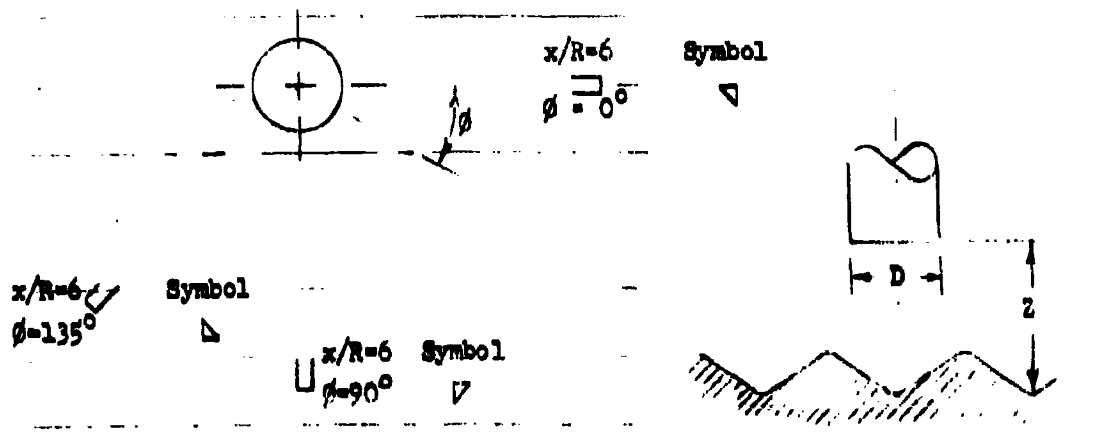
This data refers to test number 25 which was conducted over a plowed flat surface of lean clay.

Reference to soil condition V-A refers to all tests conducted over the fresh water.

Particle Trap Location

Soil Condition I-C, Tests 31 to 39 inclusive.

The following relation between traps and duct exit was used:



Plan View   Side View

In all other zero tilt angle tests the relative direction is unimportant and only the x/R location of the trap is given. The following notation has been used:

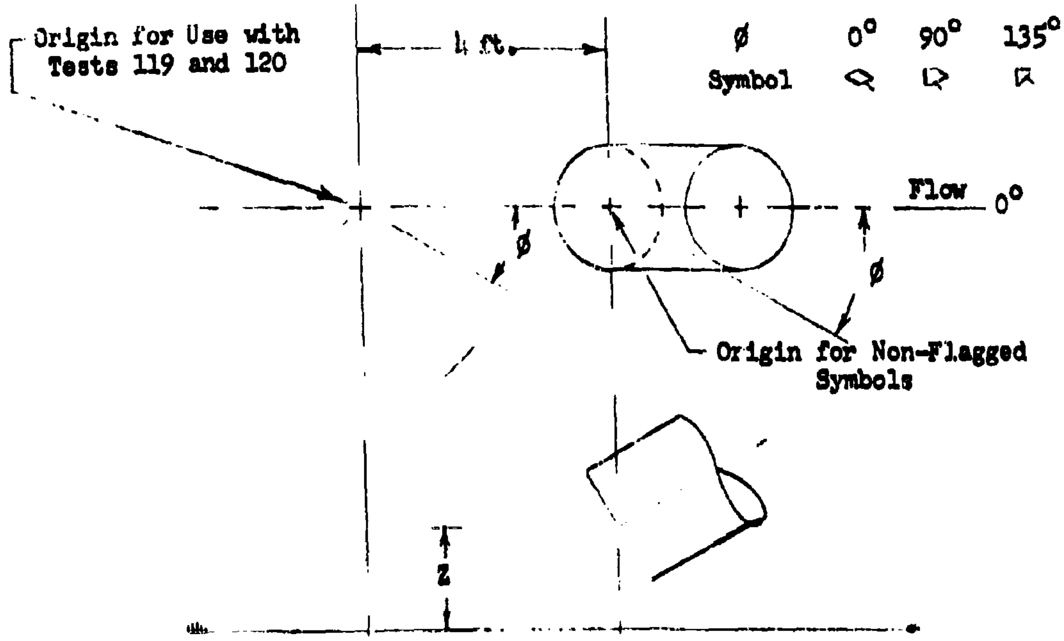
x/R	3	6	9	12
Symbol	▷	○	□	◇

The following notation was used for all tests with the thrust axis inclined to the vertical, $\theta = 30$ degree or $\theta = 60$ degree tests:

ø	0°	90°	135°
Symbol	◇	⊳	◸

For tests 119, 120 and 121 the particle traps were shifted four feet downstream. The data obtained during test number 121 was not used due to a bearing failure which necessitated premature termination of the test. The results of test numbers 119 and 120 were plotted using a flagged symbol to denote a downstream shift in the origin.

Zero Shifted 4 Feet Downstream for Flagged Symbols



Under some conditions one or more particle trap compartments were filled to capacity. When plotting the data a full compartment was designated by filling in the symbol.

1.00 SUMMARY

A two-foot-diameter ducted propeller, capable of providing disk loadings up to 145 pounds per square foot, was operated over clay soils, sand, gravel, and water. The duct exit height above the surface was set between one-half and three diameters, and the ducted propeller was accelerated to provide the test disk loading. Three particle traps were used to capture airborne material, and provide information on the flow of material at various heights above the surface.

Considerable quantities of material were removed from the impact area when tests over loose material (i.e. sand, gravel, plowed clay) were made. The quantity of material moved was primarily dependent upon moisture content, disk loading, type of soil, test time and Z/D. A test over gravel at $Z/D = 1.5$ and $w = 140$ pounds per square foot produced an erosion rate of approximately 150 pounds per second.

With the ducted propeller operating over water the onset of spray occurred at disk loadings of 8 to 15 pounds per square foot. Increasing disk loading from the spray onset loading to 140 pounds per square foot increased the spray density and height above the surface.

Sites covered with vegetation and undisturbed hard surfaces showed little or no erosion resulting from tests with disk loadings to 145 pounds per square foot. Tall grass deflected the outward flowing air, causing the flow to lift above the surface. The size of the resulting depression in the grass increased with disk loading.

2.00 CONCLUSIONS

In general there is no definite point in disk loading, or diameters above the surface, where it can be said that there exists a practical limit due to the erosion problem. The surface erosion is increased by increasing disk loading or by decreasing Z/D.

The soil condition and moisture content have been found to have a pronounced effect on erosion. Dry sand erodes quite rapidly at disk loadings of eight and above, while sand saturated with water shows only light erosion at a disk loading of 145 pounds per square foot. The erosion of gravel was retarded by saturation with water, but saturating gravel with water was not nearly as effective a deterrent as it was with sand.

The operation of the two-foot ducted propeller over grass showed the grass to be effective in preventing soil erosion; however, the tall grass formed a cup that directed the surface flow up and loose material was blown back into the duct inlet by surface winds.

Tests conducted over water showed a spray onset in the neighborhood of eight to fifteen pounds per square foot loading. Between the disk loadings of 30 and 60 pounds per square foot the spray pattern changes from a radial surface spray to one in which there is considerable vertical motion and ingestion into the duct inlet.

3.00 INTRODUCTION

The operation of helicopters and vertical lift types of aircraft from unprepared surfaces presents problems associated with the downwash or slipstream impingement. Among these problems are the effects on: the pilot; the aircraft physically and operationally; tactical operation of the aircraft; and danger to ground personnel and equipment, resulting from dust and debris set in motion by the downwash or slipstream.

In 1958 the U. S. Army Transportation Research Command (TRECOM) awarded to Hiller Aircraft Corporation Contract DA 44-177-TC-500 to study the characteristics of the downwash from VTOL aircraft. In the tests of this program the downwash from propellers and a ducted fan was impinged on a flat non-eroding surface and velocity profiles and flow directions were obtained (reference Hiller Report No. 60-15).

In April 1960 Contract DA 44-177-TC-655 was awarded Hiller Aircraft Corporation to conduct additional tests and evaluation of the effects of the downwash impingement on a variety of soil conditions. For complete soil description see Appendix I.

To obtain information that would allow even the most general answers to questions concerning problems that might arise on this subject would require an enormous amount of testing. When one considers the variables connected with the air jet generator - for example, jet velocities and shapes, pulsations, impingement angles, heights above the surface, ground winds present - and adds the variables present when considering possible landing areas (such as soil type as to textural and plastic qualities, moisture content, surface irregularities and changes in the surface during impingement of the jet) it becomes immediately apparent that the program covered by this report could only lead, at best, to very general results and possibly point the way for future test work. The reader is cautioned that the results presented in this report were obtained under conditions that allowed only a few of the many above-mentioned variables to be controlled or investigated and that any attempt to apply these results to specific cases, except in a very general way, is not recommended.

4.00 DESCRIPTION OF TEST EQUIPMENT

4.01 TRUCK TEST RIG (FIGURE 1)

A U. S. Army Model M-54, 5-ton, 6x6 cargo truck with a front-mounted winch was used as a base for the test rig. A parallelogram boom, with main arms 14½ feet long, was mounted to the truck bed. Supported on the arms was a Ford Model 332 industrial V-8 engine, displacement 332 cubic inches, continuous horsepower rating 128 at 2800 rpm. A five-speed, truck-type gearbox was mounted on the engine and provided input to output ratios of 1:1, 1.48:1, 2.40:1, 4.38:1 and 7.58:1. The output shaft from the gearbox was attached to a right angle drive unit with an input to output ratio of 1:2.69. This unit was mounted so the output end could be rotated about the main drive shaft axis. This allowed the thrust axis to be inclined from 0 to 90 degrees in 30 degree increments. The propellers were mounted on the output shaft.

The propeller height above the ground was controlled by raising and lowering the boom assembly with the winch cable. This height could be varied from six inches to 14.5 feet.

4.02 DUCTED FAN ASSEMBLY (FIGURE 1)

Disk loadings up to 145 pounds per square foot were obtained with the two-foot-diameter ducted fan assembly. The single rotation propeller contained six RAF-6 airfoil section blades machined from aluminum alloy forgings mounted in a split hub that allowed the pitch of each blade to be ground adjusted. Complete design information for the duct and propeller blades will be found in Hiller Report 60-15. The three-foot-long duct was turned from a laminated cylinder of sugar pine. It was mounted to the main support shaft by a welded tubular steel support. Mounted to the duct below the propeller was a set of five molded plastic straightening vanes designed to remove the swirl from the exit air stream.

4.03 INLET SCREEN

A duct inlet screen of 1/4-inch mesh was constructed and fitted over the duct support tubes to prevent solid particles from falling into the duct inlet. The screen did not completely close the inlet, an annular space between the outside of the duct and the bottom of the screen being left open.

Figure 1. GENERAL ARRANGEMENT, TEST EQUIPMENT

4.04 TACHOMETER (FIGURE 2)

A Hewlett-Packard Model 500C electronic tachometer was used to determine accurately the propeller rpm. The tachometer uses a photo cell to sense intermittent reflected light from the propeller drive shaft.

4.05 CAMERAS

The cameras utilized on this program consisted of a 35 millimeter camera used for all black and white test photographs of particle movements and eroded sections, and a 16 millimeter movie camera used for photographing some typical test set ups and test runs.

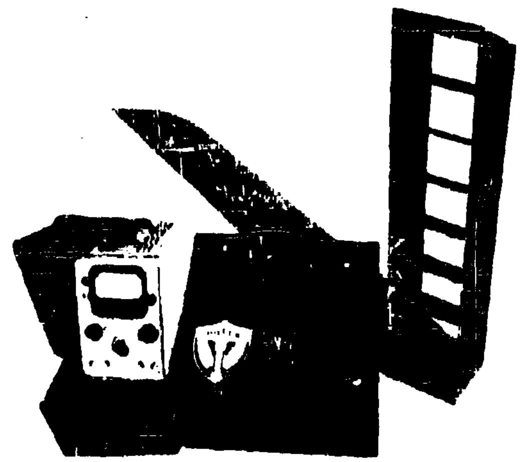


Fig. 2. Instrument Panel and Particle Trap

4.06 PARTICLE TRAPS

Two types of particle traps were used in the program. To obtain measurements of flow rates at different x/R's and h/D's three traps thirty-two inches high, six inches wide and six inches deep were constructed of 1/4-inch plywood. The back was covered with plexiglass (see Figure 2). The three traps were placed together after each run and photographed to record their contents. Larger traps six feet tall, two feet wide and one foot deep constructed of steel angle framework and covered with screen (see Figure 1) were used to trap particles and debris farther from the duct center line and at higher h/D's.

4.07 INSTRUMENT PANEL (FIGURE 2)

A portable instrument panel containing the controls for the propeller power plant was used. Mounted on the panel were the ignition switch, the starter switch, the throttle control, the camera remote control switch, the clutch controls, an engine tachometer, and a gage for measuring barometric pressures.

4.08 BACKGROUND (FIGURE 1)

The background was provided to aid in evaluating the dust clouds and particle movement patterns. It was constructed of No. 102 Black, Vat Dyed Army Duck, six feet wide and 18 feet long and supported on wooden poles spaced every six feet. These poles were inserted into hollow steel stakes driven into the ground. White lines were painted every two feet on the background to provide a visible scale. The background was installed on a radial center line of the duct with the lower edge approximately one foot above the ground and the first mark six feet from the duct center line.

4.09 WAVE RODS AND RECORDERS (FIGURES 3 AND 4)

Five wave rods were supplied by the U. S. Army Engineers, Waterways Experiment Station. The essential elements of the two-foot-long wave rods are the two stainless steel wires supported by insulating material. These rods were submerged in the water to a depth of approximately one and one-half feet. The wave rods were used as sensing elements in parallel to a portion of a balanced full bridge. An unbalance, caused by changes in the water height, was reflected to the bridge, amplified, and recorded on a direct writing oscillograph. The bridge consisted of four 120 ohm and four 50 ohm precision resistors, making a 170 ohm bridge. The sensing elements were parallel to one of the 50 ohm resistors in one leg of the bridge to give a very small change in resistance for a submergence of two feet in water. A small resistance change was desirable so that the calibration curve would be approximately linear.

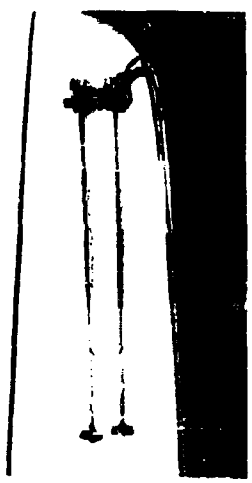


Fig. 3. Wave Rods

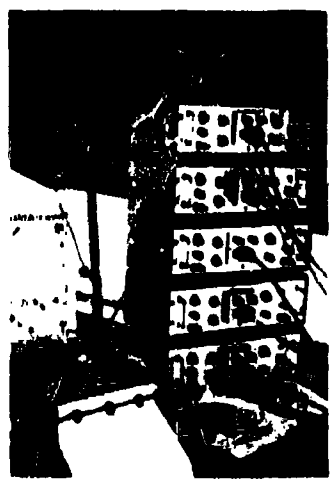


Fig. 4. Recording Equipment
Wave Rod

5.00 EXPERIMENTAL PROCEDURES

5.01 SOIL SURFACE

The general arrangement shown in Figure 1 was used for soil conditions I-B, I-C, III and IV. The background was aligned, before each test, with the anticipated flow so as to provide for minimum disturbance. Particle traps were placed in the impingement area as indicated in the list of symbols. No particle traps were used for tests conducted over soil conditions I-A, II and V, and only the large traps were used for tests over soil conditions I-D and I-E. In general the large traps proved unsatisfactory and the data has not been used.

5.02 WATER TESTS

The arrangement of equipment used for the water tests is shown in Figure 5. A spacing of one foot was used between each of the five wave rods described in Section 4.09. The wave rods were located along a radial line, or on the plane of inclination, with the first wave rod under the duct centerline for zero degree thrust axis inclination tests. When the thrust axis was inclined the wave rods were positioned so as to best survey the impact area.

Fig. 5. Water Site Test Equipment

5.03 OPERATING PROCEDURE

After preparation of the test site the ducted propeller was engaged and the disk loading increased to the desired value. The test disk loading was maintained for the test time, which varied from forty seconds to four minutes, and then the throttle was reduced and the clutch disengaged. The test time was normally one minute duration; however, to protect the propeller blades from excessive erosion, it was reduced for some tests. In a few tests the test time was extended so as to compile sufficient material in the traps for measurements. For specific test times refer to Table 1.

6.00 DISCUSSION

6.01 GENERAL

Soil classification and descriptions of test sites are given in Appendix I.

The procedure used to calculate the flow rate was as follows: After each test the depth of material trapped in each compartment of the three small traps was measured. From the geometry of the traps, and the depth of material, the volume of the trapped material was calculated. The density of the trapped material was assumed to be the same as that of the uppermost soil sample. With this assumption the weight of the trapped material could be estimated. The weight of material which passed through a square foot of area each minute was obtained and plotted as flow rate. The test time was normally one minute; however, some tests were conducted for more or less than one minute. The flow rate was always based on the actual test time and assumes a constant rate of erosion.

Many tests produced an eroded hole. When the test was completed the hole diameter and depth were measured. For tests over the unmowed grass where the concavity existed only during operation, the diameter was estimated. The hole diameter to duct exit diameter ratio versus disk loading was then plotted.

6.02 VOLUME LOADING (V.L.)

The grain size of soil condition IV varied over a large range, .007 millimeters to 40 millimeters. Therefore, plots were required to provide information on the relative size of particles trapped. It was felt that the shape of the particle had some influence on the maximum height to which it would be projected. The volume loading notation was chosen to reflect the shape of the particle. Volume loading is defined as the quotient resulting from a division of the particle volume by its maximum projected area. If the density of each particle were known, the product of volume loading and density would result in a parameter similar to the wing loading of an aircraft. For this report the particles were assumed to be rectangular objects whose principal dimensions were established from the particle size. By assuming each particle to be a rectangular parallelepiped the volume loading became equal to the minimum dimension of the assumed object.

6.03 SOIL CONDITION I, LEAN CLAY (C.L.)

Section A. Bladed Section

The bladed lean clay withstood the full impact of 140 pounds per square foot disk loading with very minor erosion, Figures 6a and b. The fine surface material formed a dust cloud which was initially dense, but cleared considerably after the surface was swept clean. Small surface particles broke loose at random intervals throughout the test.

Fig. 6a. Test I-A4
During Operation

Fig. 6b. Test I-A4
After Completion

Section B. Plowed Section (Flat)

Twenty-five tests were conducted over the plowed flat section. The higher disk loading tests removed large quantities of material and produced dust clouds of sufficient size and density to obscure the test equipment, see Figures 7a and b.

Fig. 7a. Test I-B15
During Operation

Fig. 7b. Test I-[illegible]
After Completion

The data obtained from the particle traps was converted to flow rates, as described in Section 6.01 and plotted in Figures 19 ... After completion of the test the diameter of the eroded hole was measured. The ratio of the hole diameter to duct exit diameter has been plotted versus disk loading, Figure 41.

Section C. Plowed Section (Furrowed)

Nine tests were conducted over the plowed and furrowed lean clay; the furrows were prepared as described in Appendix I. The higher disk loading tests removed all loose material in the impingement area, with noticeable dust motion along the bottom of the furrow, Figure 8. Flow rates obtained from tests over the plowed and furrowed lean clay are shown in Figures 42 to 48. The test data for Figures 47 and 48 was obtained after sprinkling the surface with water (see Appendix I, Tests 37 and 38, for soil descriptions).

Fig. 8. Test I-... During Operation

Section D. Grassy Area (Unmowed)

The small traps were not used for the ten tests conducted over the grassy area. The unmowed grass deflected the downwash, under all disk loading conditions, Figure 9a. The jet blast removed all loose material on the ground surface and broke off and blew away some of the grass, but did not disturb the grass roots or hard soil.

Fig. 9a. Test I-16 During Operation

The loose material which was lifted above the [illegible] by the air stream [illegible] some matting [illegible] duct inlet. [illegible] 9b. The de[illegible] [illegible]on in the tall grass showed a definite circular shape whose diameter was estimated during each test, the results of which are shown by Figure 49.

Fig. 9b. Grass Mat Duct Inlet Screen

Section E. Grassy Area (Freshly Mowed)

Seventeen tests were made over the freshly mowed grassy area; however, no quantitative data was obtained. The higher disk loading tests (100 to 145 pounds per square foot) removed all the loose material from the impact area, leaving the roots and hard soil unaltered, Figure 10. The primary difference between the mowed and unmowed grass was the deflection of the jet above the ground by the unmowed grass.

Fig. 10. Test I-E82 After Completion

6.04 SOIL CONDITION II. FAT CLAY (C.H.)

Sections A and B. Weathered and Bladed, Respectively

Four tests were made over the weathered fat clay and one after blading the same section. No particle traps were used during tests over the fat clay as there was no steady erosion. The weathered (Section A)

fat clay was peeled by the jet impingement, small dry surface chunks broke free and were blown from the area, Figures 11a and b. After blading the dry crust from the surface one test at 135 pounds per square foot was made. The only soil movement consisted of a few loose particles left by the track of the motor patrol (grader), Figure 12.

Fig. 11a. Test II-A91
During Operation

Fig. 11b. Test II-A91
After Completion

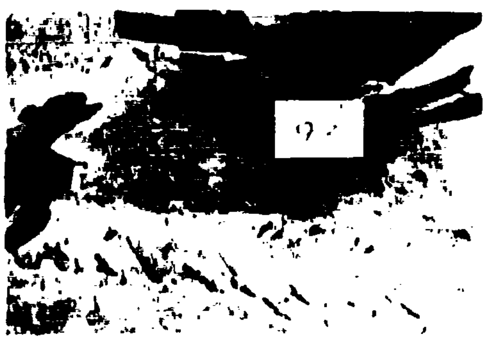


Fig. 12. Test II-B93
After Completion

6.05 SOIL CONDITION III, SAND (S.P.)

Section A. Dry Sand

Twenty-eight tests were made over the dry sand. The dry sand was considered to provide an ideal test site, as it was relatively homogenous and reproduceable, and considerable activity was produced by the jet impingement, Figures 13a and b. The flow rates were

Fig. 13a. Test III-A108 During Operation

Fig. 13b. Test III-A108 After Completion

calculated and plotted in Figures 50 to 64 for the thrust axis normal to the ground plane, in Figures 65 to 72 for 30 degree thrust axis inclination, and in Figures 73 and 74 for 60 degree thrust axis inclination. During the tests over the dry sand, it was noticed that two eroded holes were formed, one large almost imperceptible depression, with a smaller diameter deep hole in the center. The diameter of both depressions was recorded and plotted as depression diameter to duct exit diameter ratio versus disk loading, Figure 75.

Section D. Wet Sand

The addition of moisture (wet sand condition described in Appendix I) to the sand had a pronounced effect on the behavior of the erosion. The jet impingement appeared to dry and then erode the surface at a slow rate, Figures 14a and b. Tracks which were not visible before

Fig. 14a. Test III-B43 During Operation

Fig. 14b. Test III-B43 After Completion

testing were exposed during the test. It appeared that local loading of the surface tended to squeeze the water out, which produced faster drying and erosion during the test. By comparing the flow rates produced by tests over wet sand, Figures 76 and 77, and those over dry sand, Figures 59 and 64, at similar conditions, the decrease in erosion rate obtained by saturating sand with water is obvious.

6.06 SOIL CONDITION IV, SANDY GRAVEL (G.W.)

Section A. As Deposited

Seventeen tests were conducted over this soil condition. The effect of the eroded hole on the air flow pattern is shown in Figures 15a, b and c.

Fig. 15a. Test IV-A63, During Initial Operation

Fig. 15b. Test IV-A63 After 30 Seconds of Operation

Fig. 15c. Test IV-A63 After Completion

Figure 15a was taken during the first few seconds of the run which was at a Z/D of 1.5 and a disk loading of 140 pounds per square foot. The photograph in Figure 15b was made after about thirty to thirty-five seconds of running time. The eroded hole shown in Figure 15c was the result of a total run of forty-two seconds. By computing the volume of material removed and using the average material density, a total erosion rate of approximately 150 pounds per second was obtained. From observations of the test it was obvious that the particle traps caught most of the trapped material during the initial twenty to thirty seconds; however, as the flow rate into the trap varies with time by some unknown function, the flow rates plotted (Figures 78 to 93) are average values based on total test time.

The curve of the eroded hole diameter to duct exit diameter versus disk loading (Figure 94) includes the test data of Soil Condition IV-A and IV-B.

In addition to the flow rate and eroded hole diameter curves, figures of volume loading versus h/D (Figures 95 to 110) have been included. The increased volume loading at low h/D values indicates that larger particles (by the definition of volume loading) were captured near the surface.

Section B. Sprinkled and Compacted

Eleven tests were run over this section. The difference in the erosion rate between Section IV-A and Section IV-B was noticeable during testing (Figures 16a and b).

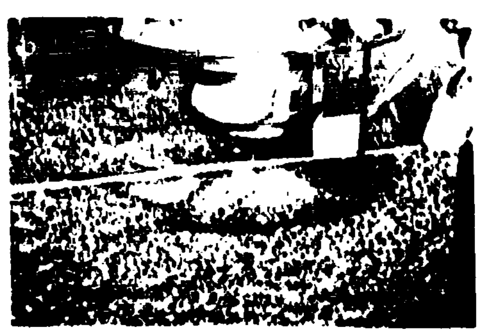


Fig. 16a. Test IV-A123 After Completion

Fig. 16b. Test IV-B132 After Completion

By comparison of the flow rates for Section IV-B (Figures 111 to 121) with those of Section IV-A (Figures 78 to 93) for similar test conditions, it can be seen that the additional moisture and/or the compacting reduced the erosion rate. The plots of eroded hole diameter versus disk loading are included with the data of Soil Condition IV-A (Figure 94). The volume loading (Figures 122 to 132), as would be expected, appears to be very similar to those for the tests of Soil Condition IV-A (Figures 95 to 110).

6.07 SOIL CONDITION V-A. FRESH WATER

There were seven tests over the water site, most of which consisted of six disk loadings. For the water tests, wave rods were used to make a continuous record of the water level over a brief period. The wave rods and associated equipment are described in detail in Section 4.09. The impression in the water surface (Figure 17a) was measured by the wave rods, and the data has been plotted (Figures 133 to 138).

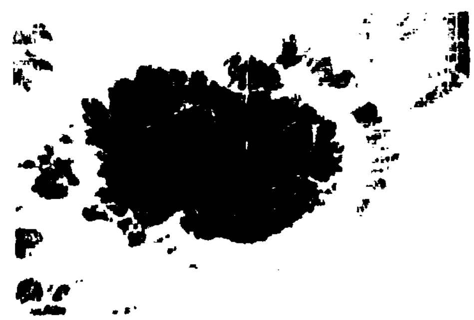


Fig. 17a. Operation at 15 Pounds per Square Foot

The duct location and tilt angle were included on compatible scales, so as to present a profile picture. The wave amplitude (Figures 139 to 144) and frequency (Figures 145 to 150) have been plotted against disk loading for each of the test conditions. The spray height was estimated from the 16 millimeter moving pictures obtained during testing and curves of h/D versus w prepared from this data, Figures 151 and 152. The higher disk loading tests produced considerable spray, Figures 17b, c, d and e.

Figures 17b, c, d, e. A preliminary test at Z/D = 2.5 over the water test site. The wave rods were not installed and a test number was not assigned.

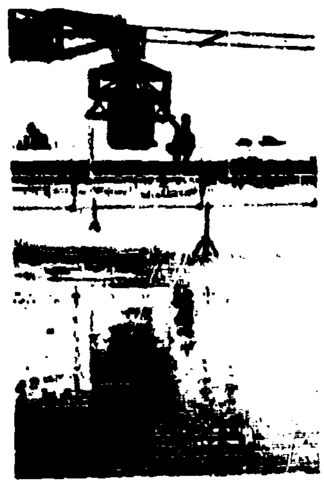


Fig. 17b. Operation at 8 Pounds per Square Foot

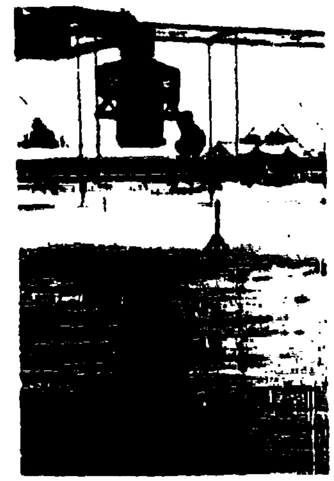


Fig. 17c. Operation at 15 Pounds per Square Foot

Fig. 17d. Operation at 60 Pounds per Square Foot

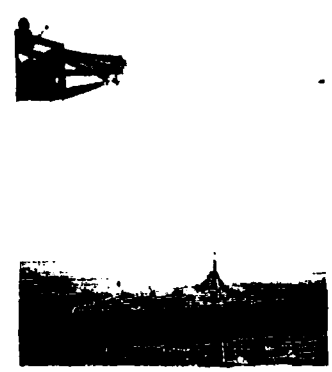


Fig. 17e. Operation at 140 Pounds per Square Foot

Examination of Figures 151 and 152 shows the onset of spray to take place at a disk loading of eight to fifteen pounds per square foot. A very rapid rate of increase in spray height with disk loading takes place from 8 to 60 pounds per square foot disk loading, beyond which the increase in h/D versus w is approximately linear.

From photographs and observation it was noted at low disk loadings that the spray is a radial surface spray which reaches its maximum height at large x/R values. At disk loadings above 60 pounds per square foot the spray has considerable vertical motion and does not spread along the surface to the extent at which it did at lower disk loadings (w = 8 to 30 pounds per square foot).

The presence of the screens and the large duct length helped retard the ingestion of water; however, sufficient amounts were ingested to retard the propeller and prevent maximum disk loading tests under the most adverse conditions (low Z/D and high disk loading), Figure 18.

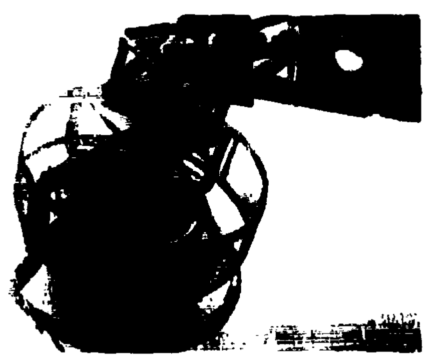


Fig. 18. Test V-A49
During Operation

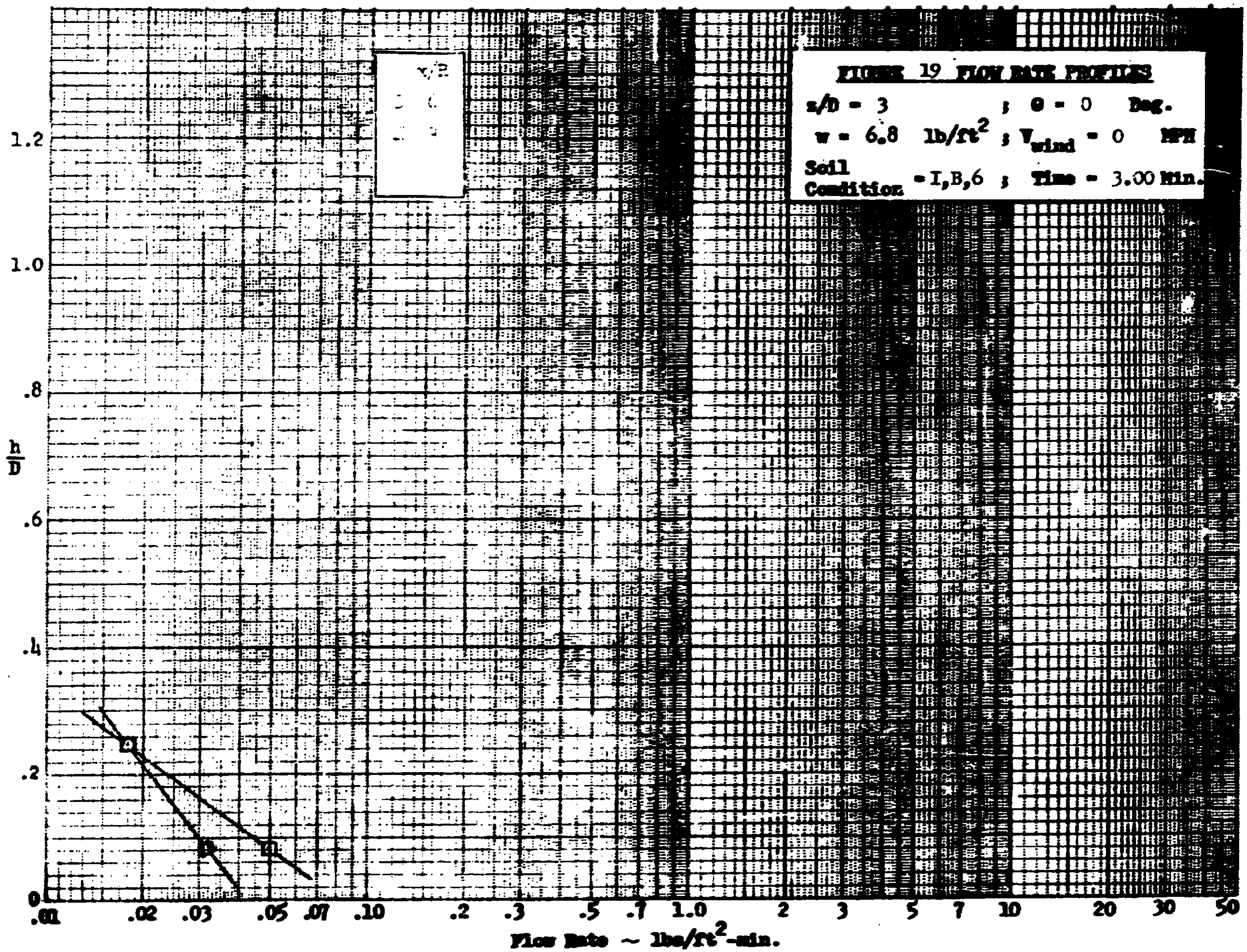


FIGURE 19 FLOW RATE PROFILES
x/D = 3 ; θ = 0 Deg.
w = 6.8 lb/ft² ; V_wind = 0 MPH
Soil Condition = I,B,6 ; Time = 3.00 Min.
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

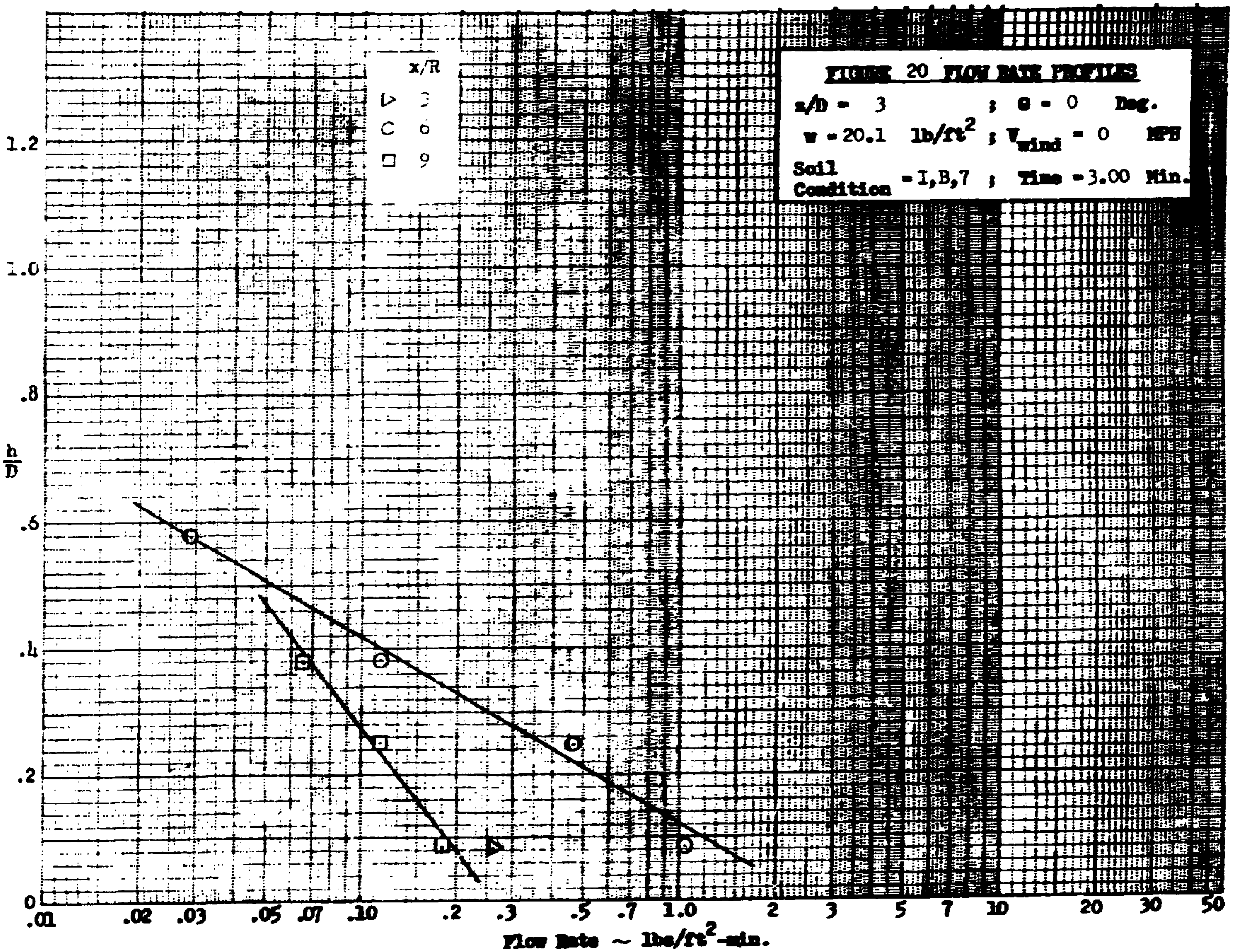


FIGURE 20 FLOW RATE PROFILES

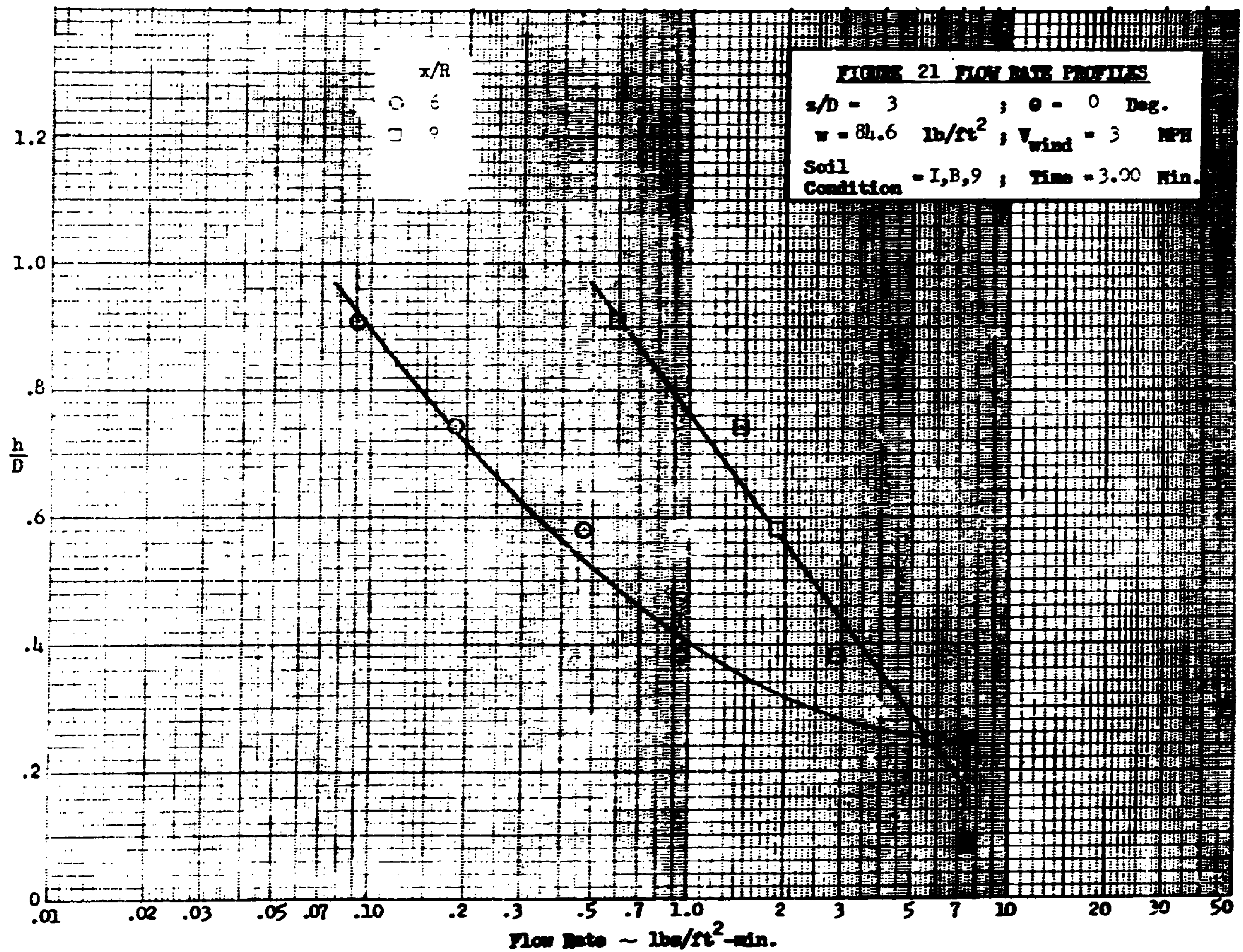


FIGURE 21 FLOW RATE PROFILES

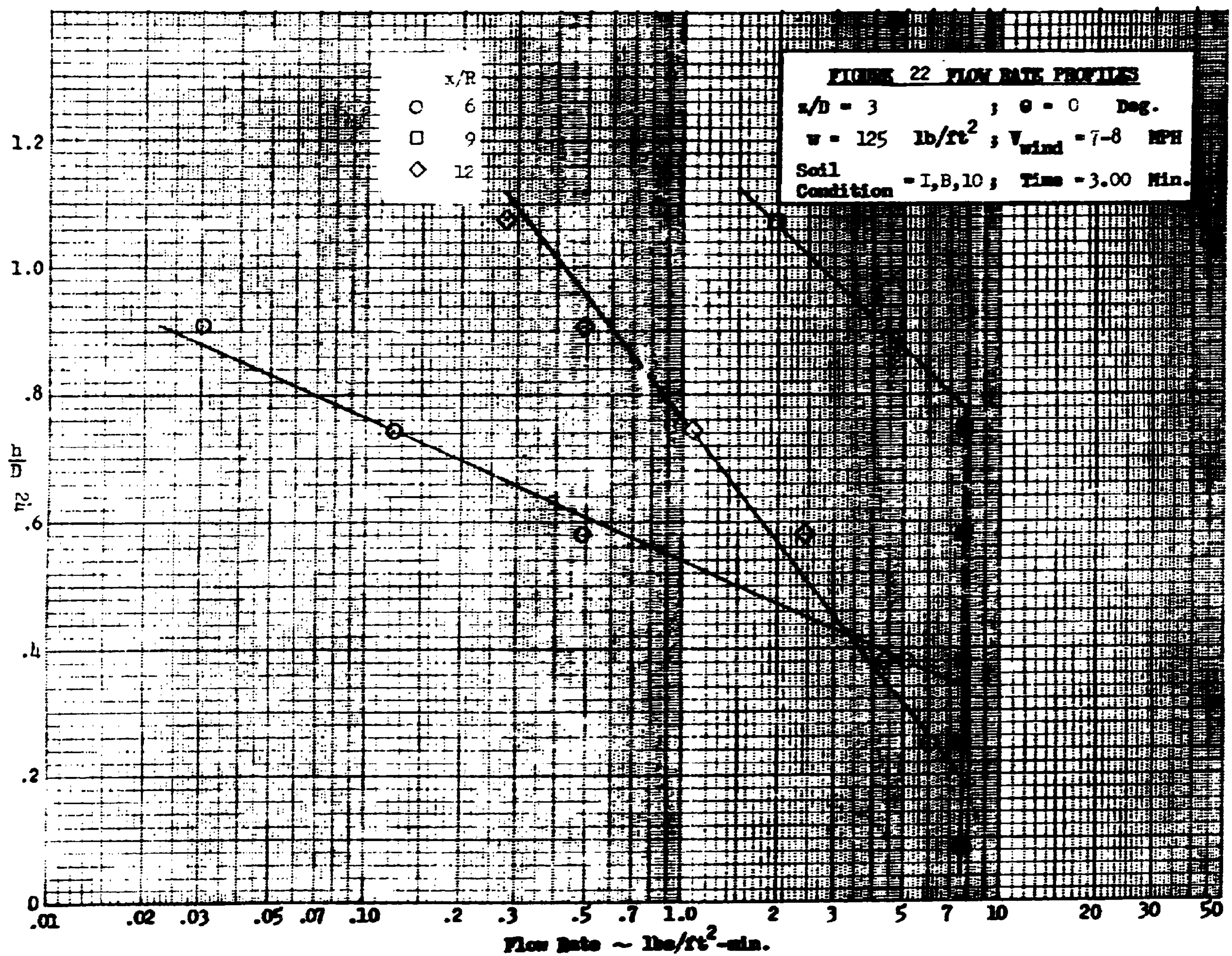


FIGURE 22 FLOW RATE PROFILES
x/D = 3 ; θ = 0 Deg.
w = 125 lb/ft² ; V_wind = 7-8 MPH
Soil Condition = I,B,10 ; Time = 3.00 Min.
x/R
○ 6
□ 9
◇ 12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.
24

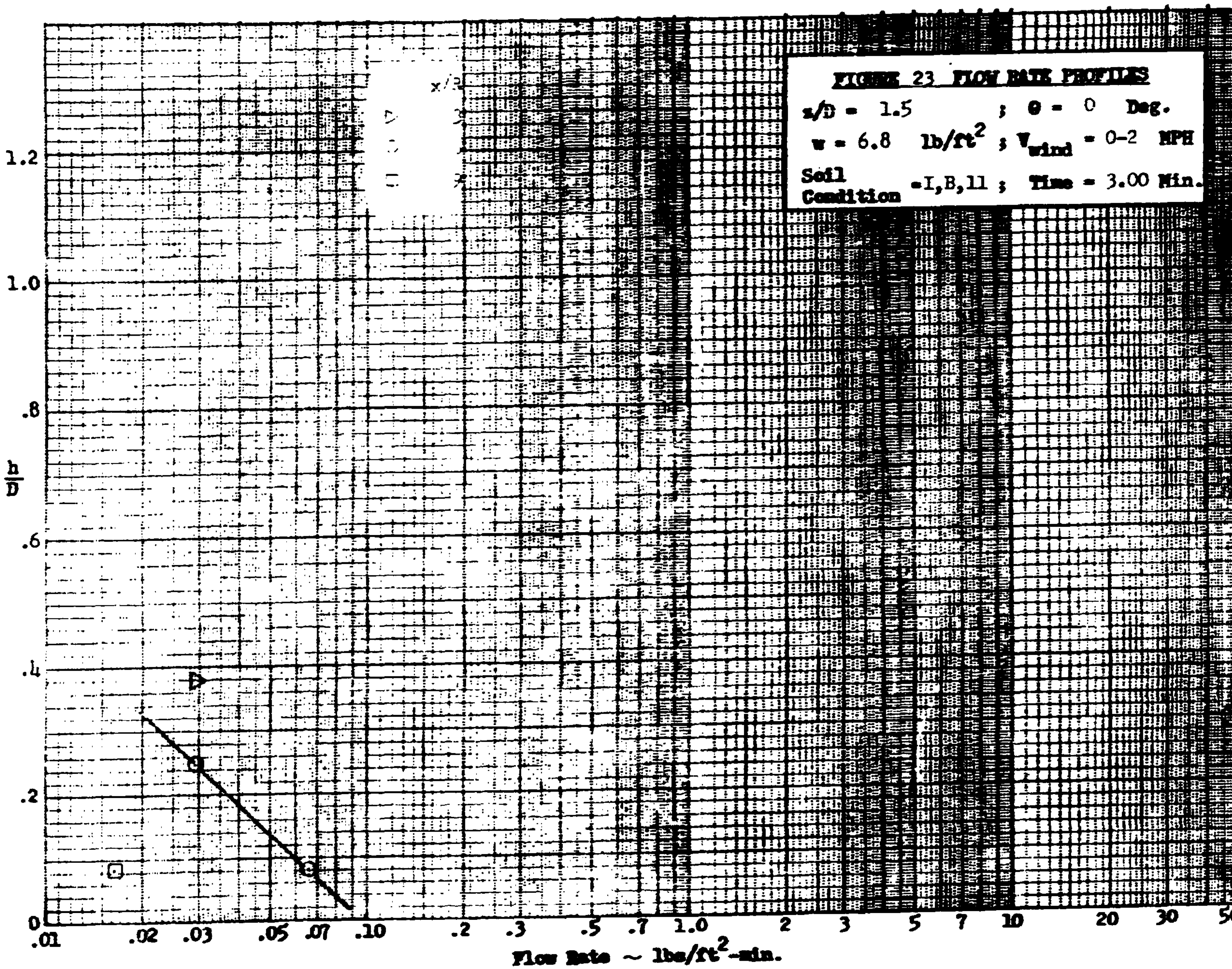


FIGURE 23 FLOW RATE PROFILES

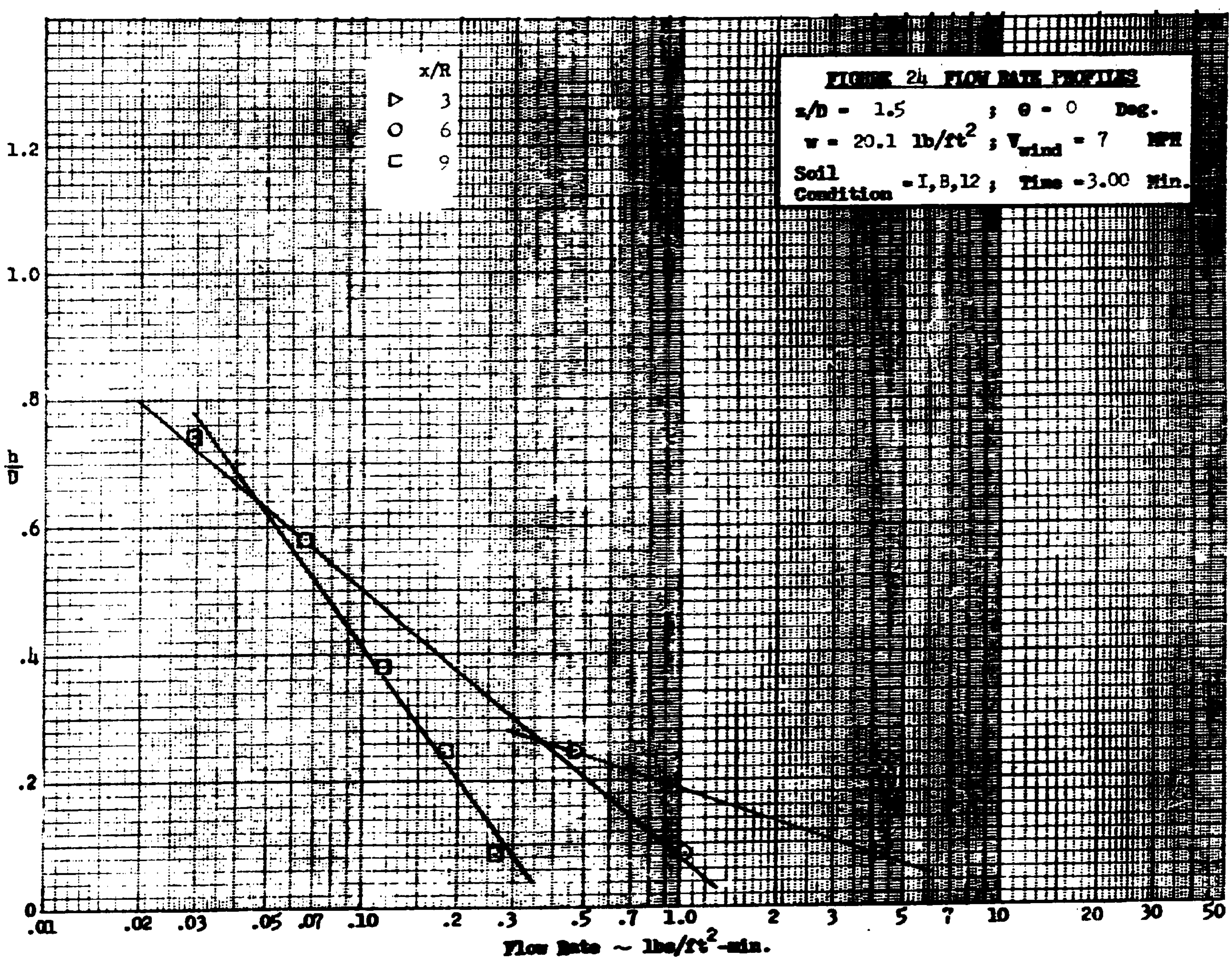


FIGURE 24 FLOW RATE PROFILES
x/D = 1.5 ; θ = 0 Deg.
w = 20.1 lb/ft² ; V_wind = 7 MPH
Soil Condition = I,B,12 ; Time = 3.00 Min.
x/R
3
6
9
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

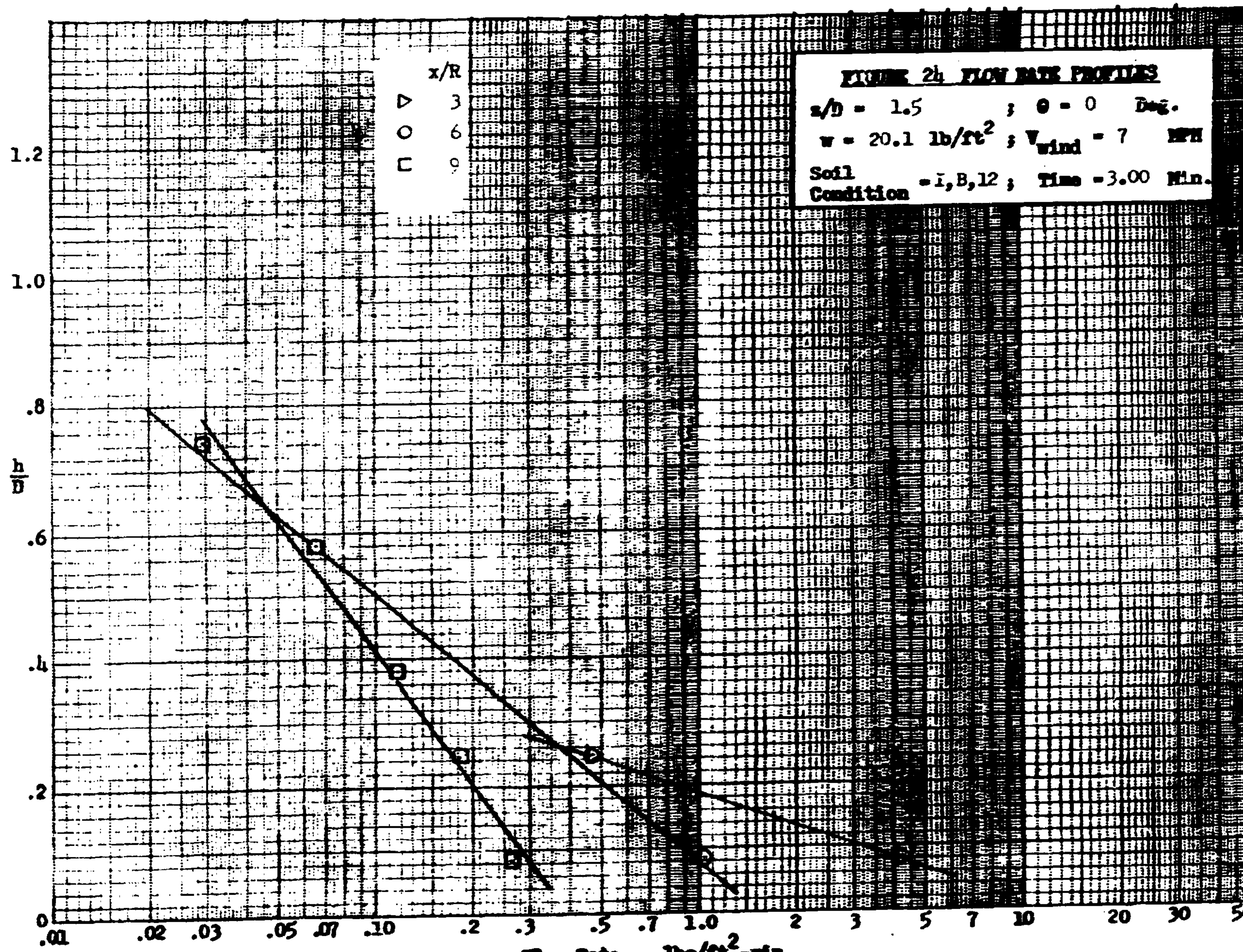


FIGURE 24 FLOW RATE PROFILES
x/D = 1.5 ; θ = 0 Deg.
w = 20.1 lb/ft² ; V_wind = 7 MPH
Soil Condition = I,B,12 ; Time = 3.00 Min.
x/R
3
6
9
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

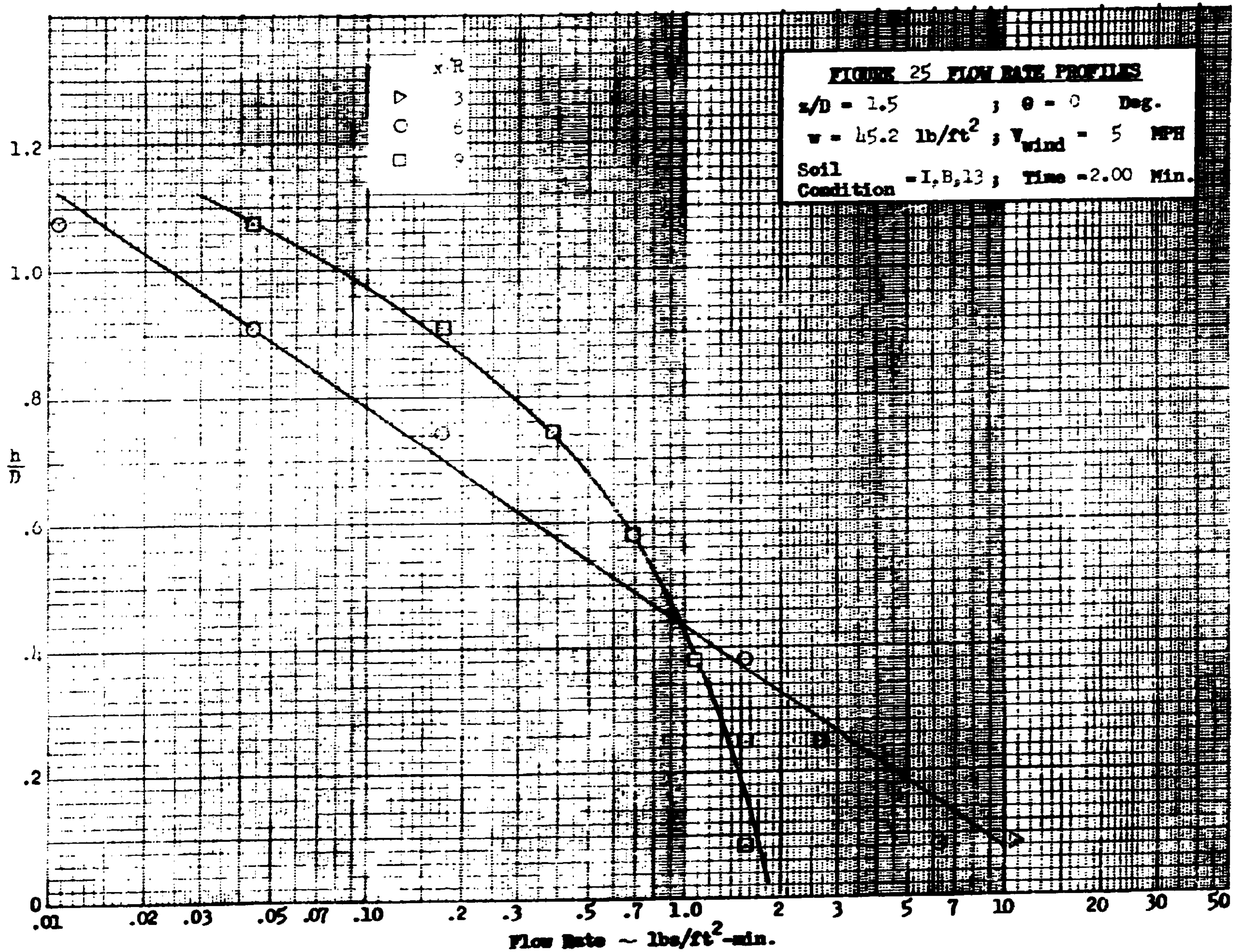


FIGURE 25 FLOW RATE PROFILES
z/D = 1.5 ; θ = 0 Deg.
w = 45.2 lb/ft² ; V_wind = 5 MPH
Soil Condition = I,B,13 ; Time = 2.00 Min.
x/R
3
6
9
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

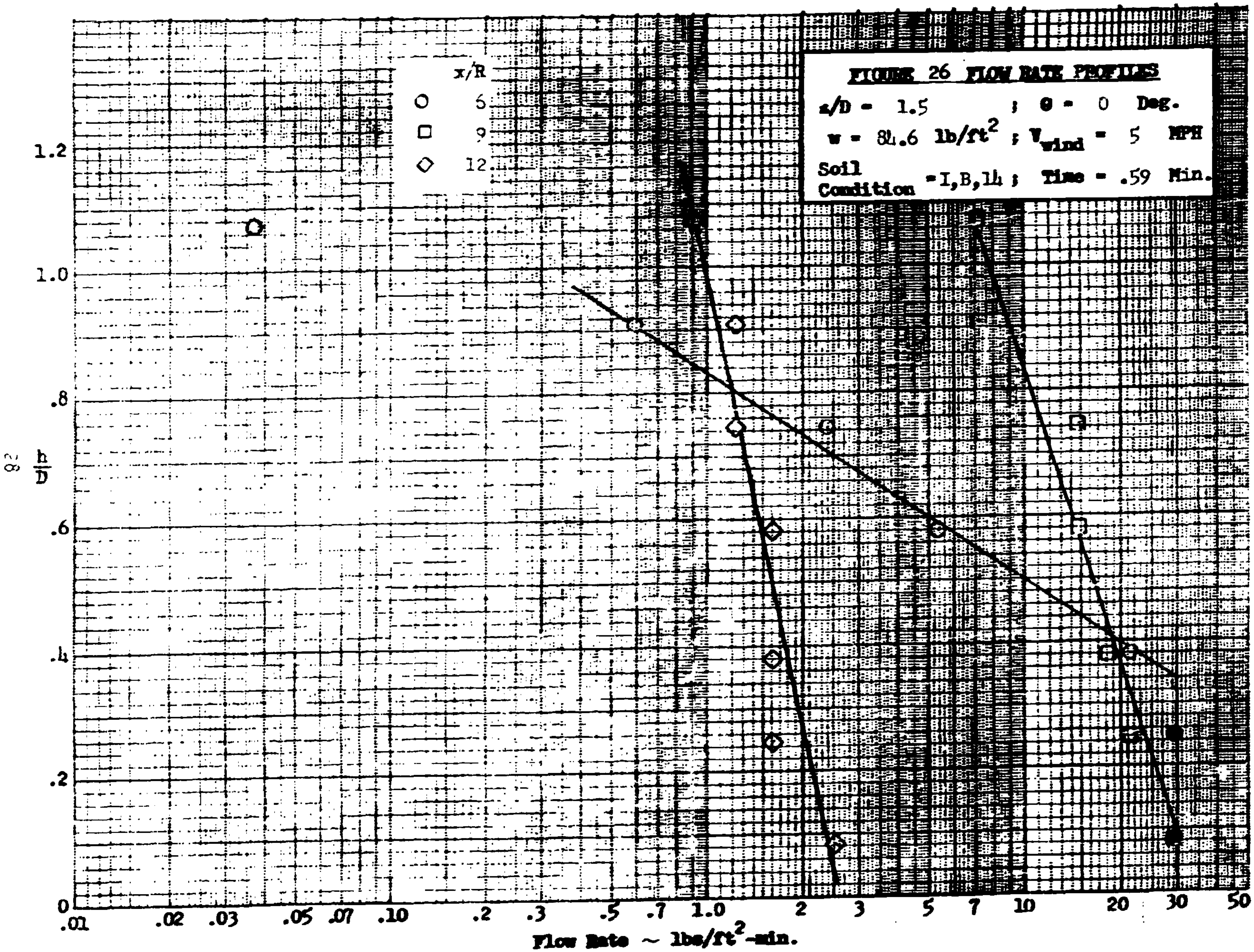


FIGURE 26 FLOW RATE PROFILES
z/D = 1.5 ; θ = 0 Deg.
w = 84.6 lb/ft² ; V_wind = 5 MPH
Soil Condition = I,B,14 ; Time = .59 Min.
x/R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

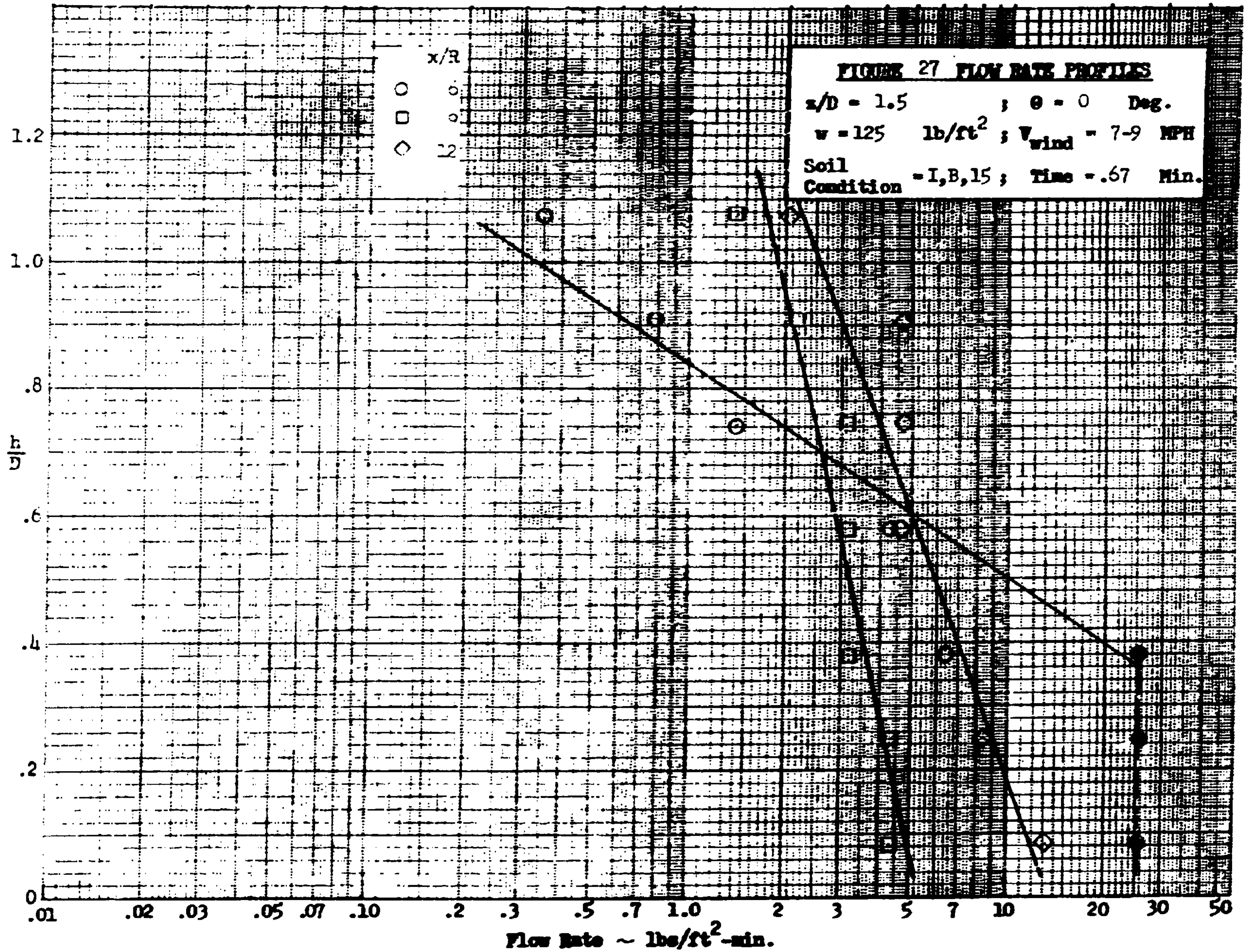


FIGURE 27 FLOW RATE PROFILES
x/D = 1.5 ; θ = 0 Deg.
w = 125 lb/ft^2 ; V_{wind} = 7-9 MPH
Soil Condition = I,B,15 ; Time = .67 Min.
x/R
0
6
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

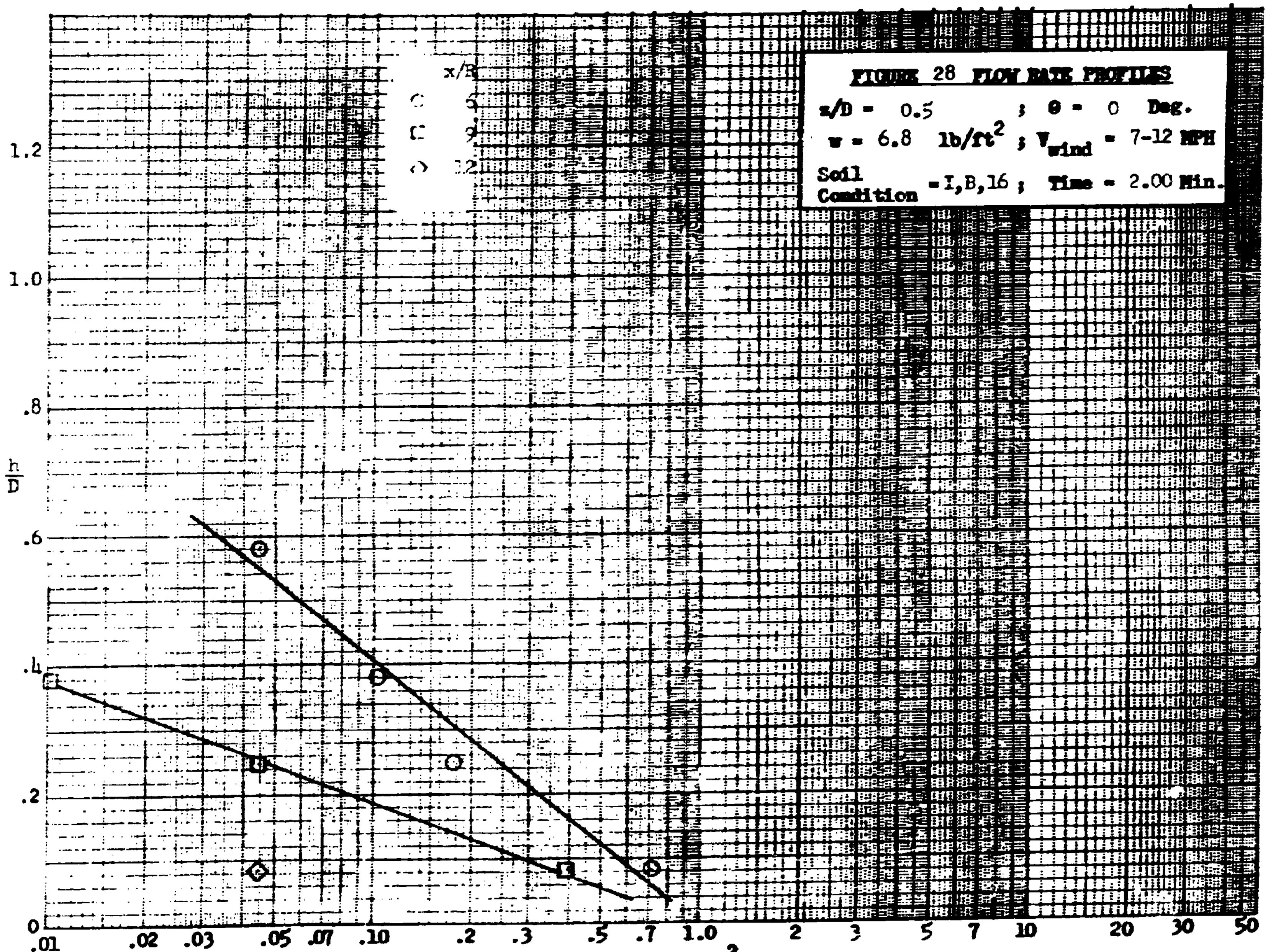


FIGURE 28 FLOW RATE PROFILES

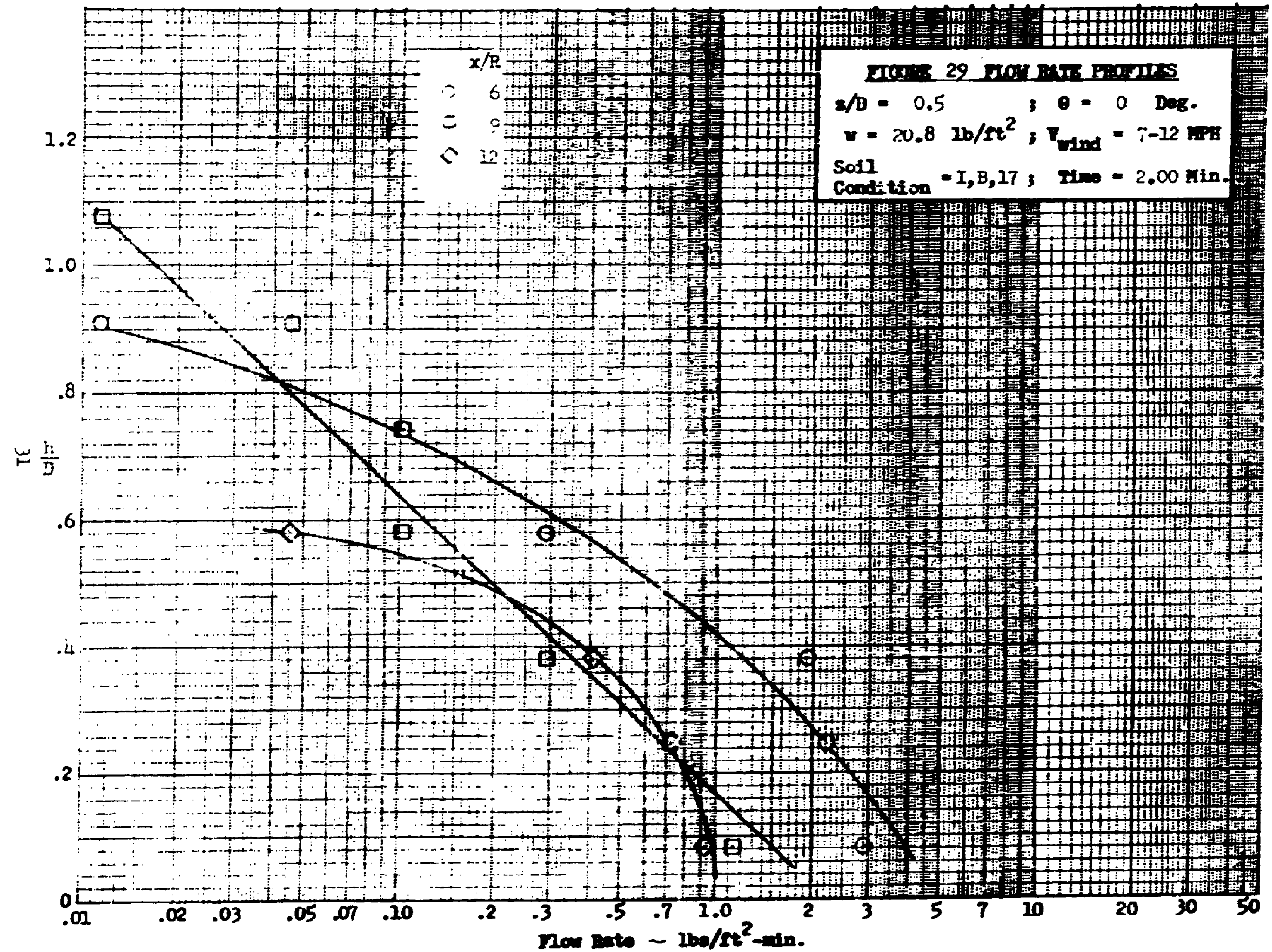


FIGURE 29 FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 20.8 lb/ft² ; V wind = 7-12 MPH
Soil Condition = I,B,17 ; Time = 2.00 Min.
x/R
6
9
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

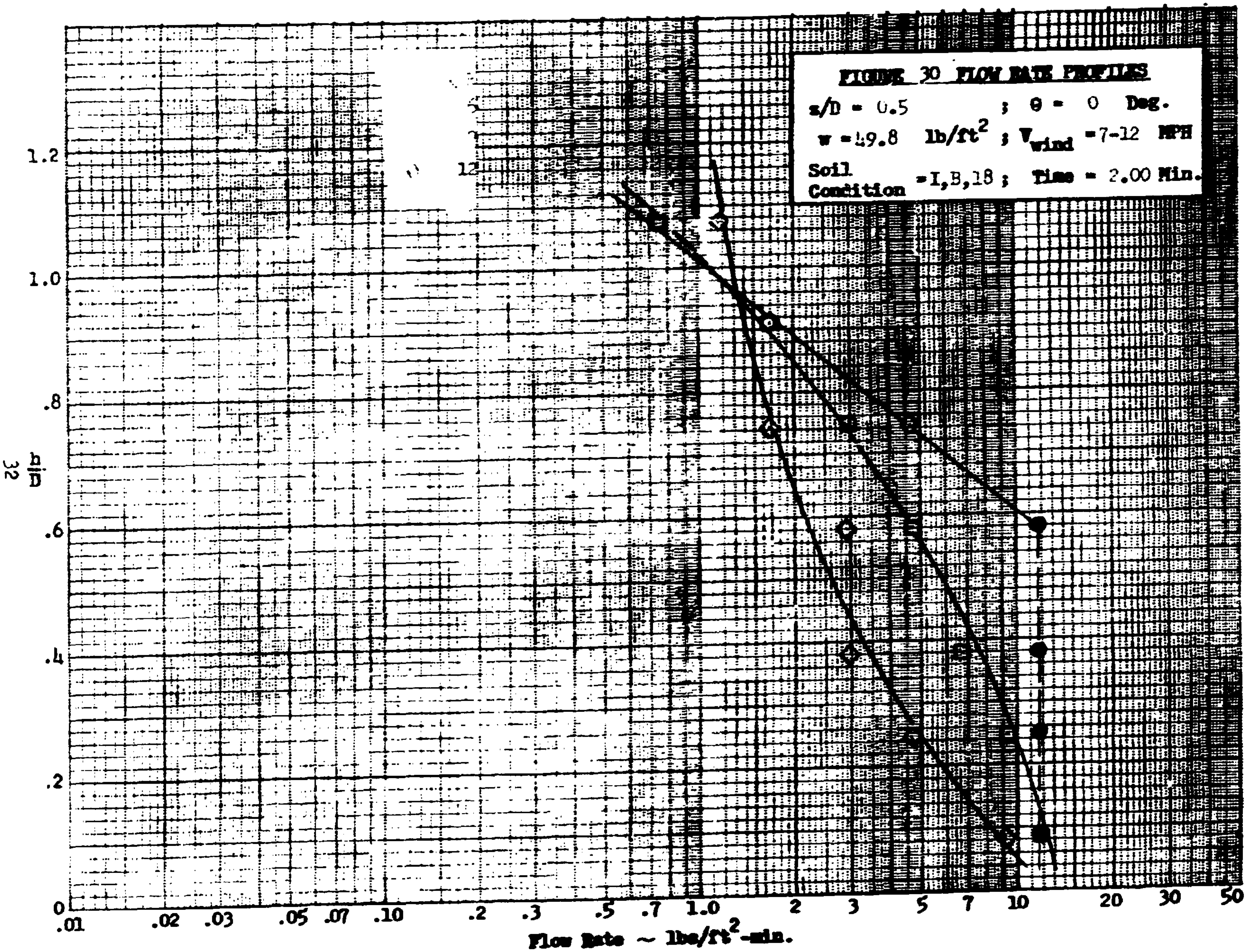


FIGURE 30 FLOW RATE PROFILES
s/D = 0.5 ; θ = 0 Deg.
w = 49.8 lb/ft² ; V_wind = 7-12 MPH
Soil Condition = I,B,18 ; Time = 2.00 Min.
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

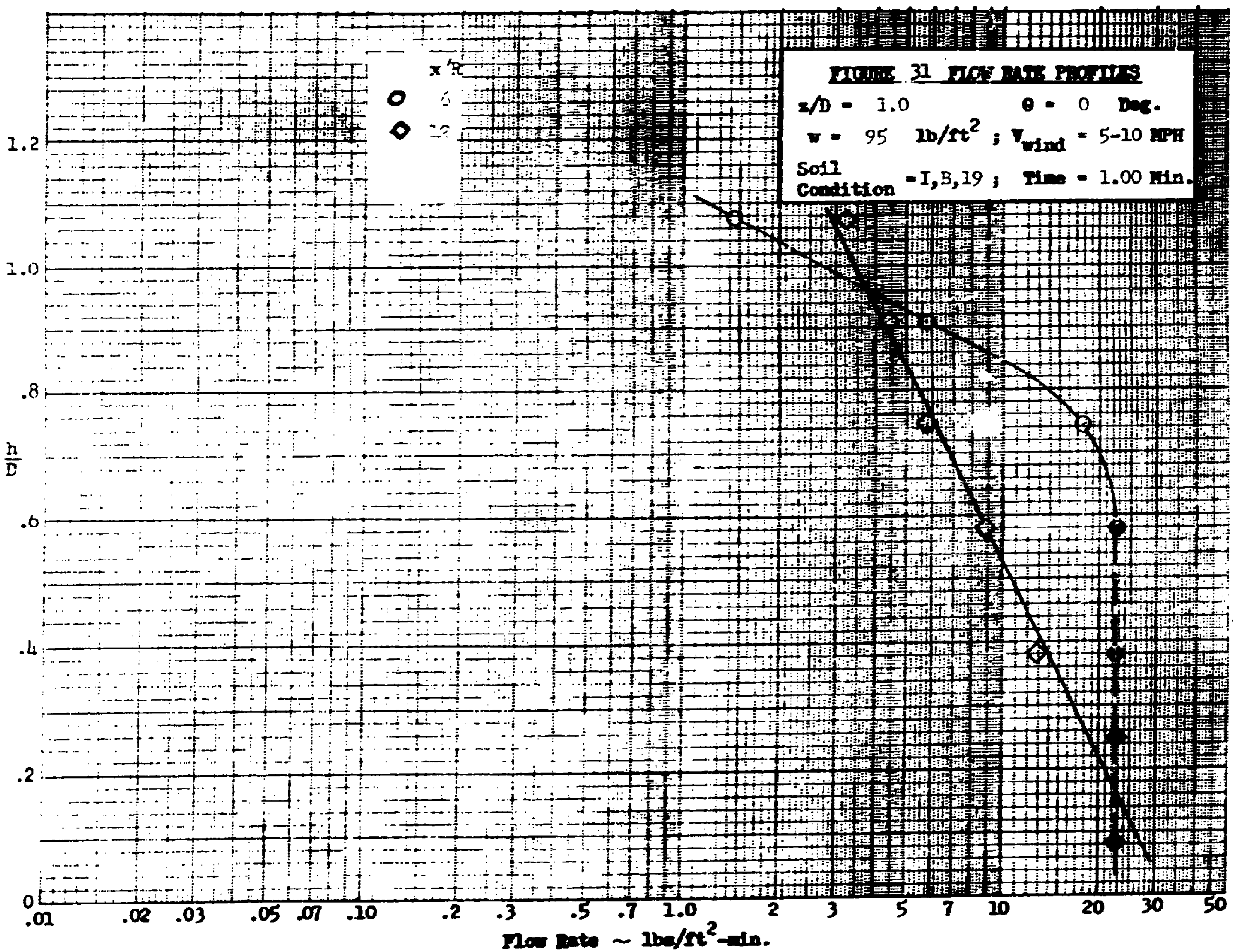


FIGURE 31 FLOW RATE PROFILES
z/D = 1.0 θ = 0 Deg.
w = 95 lb/ft^2 ; V_{wind} = 5-10 MPH
Soil Condition = I,B,19 ; Time = 1.00 Min.
x/R
6
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

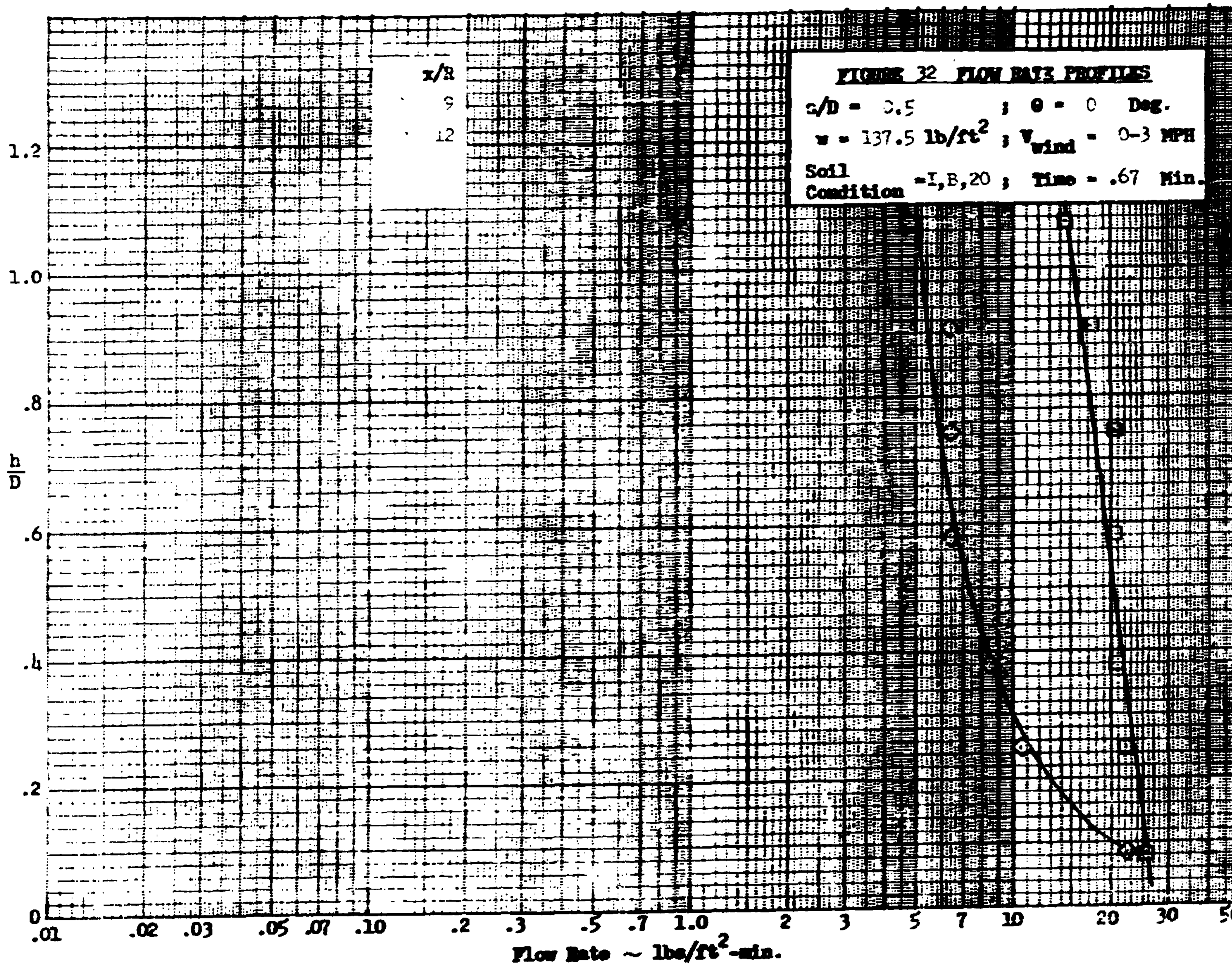


FIGURE 32 FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 137.5 lb/ft² ; V wind = 0-3 MPH
Soil Condition = I,B,20 ; Time = .67 Min.
x/R
9
12
h/D
0
.2
.4
.6
.8
1.0
1.2
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

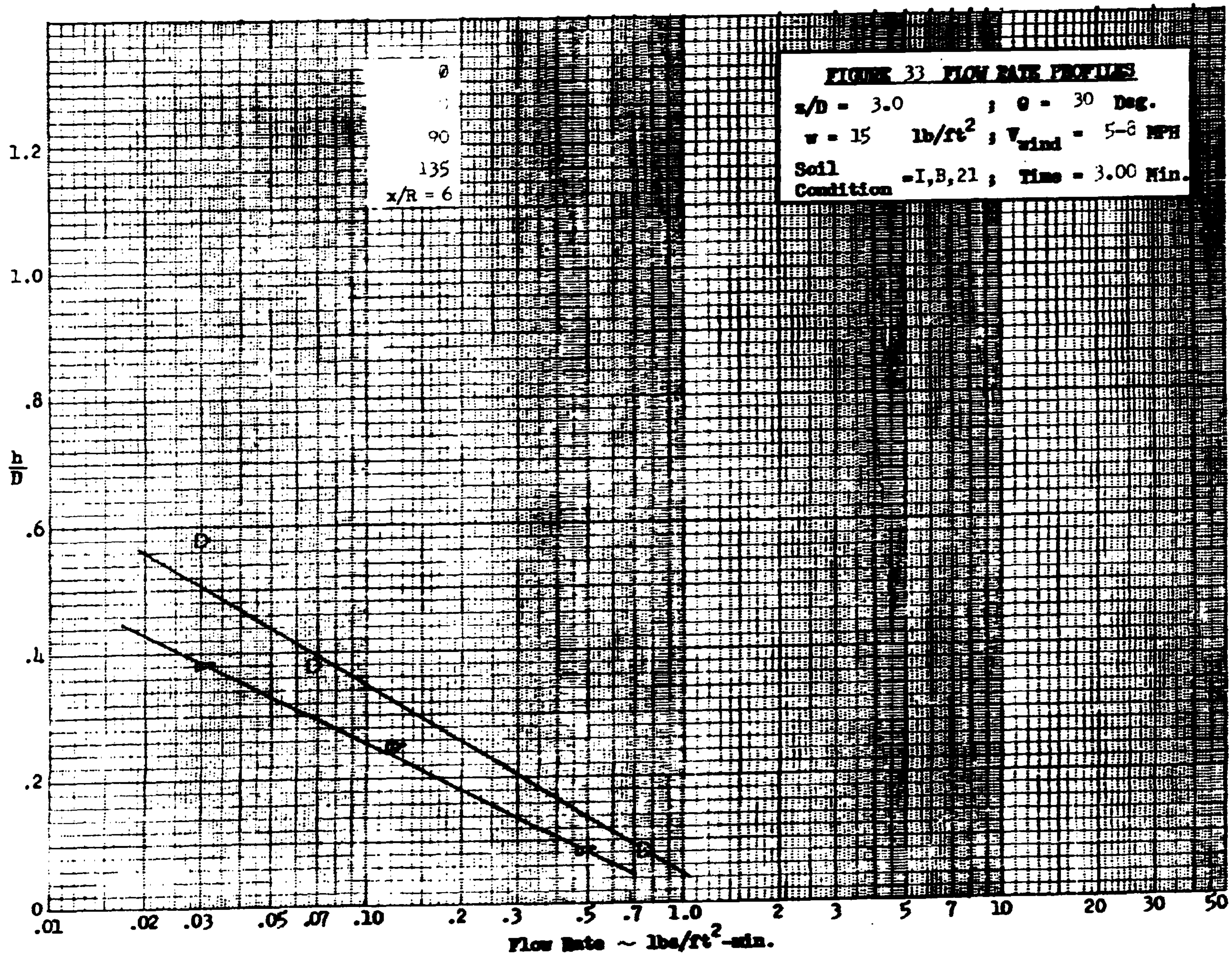


FIGURE 33 FLOW RATE PROFILES
x/D = 3.0 ; θ = 30 Deg.
w = 15 lb/ft^2 ; V_wind = 5-8 MPH
Soil Condition = I,B,21 ; Time = 3.00 Min.
0
90
135
x/R = 6
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

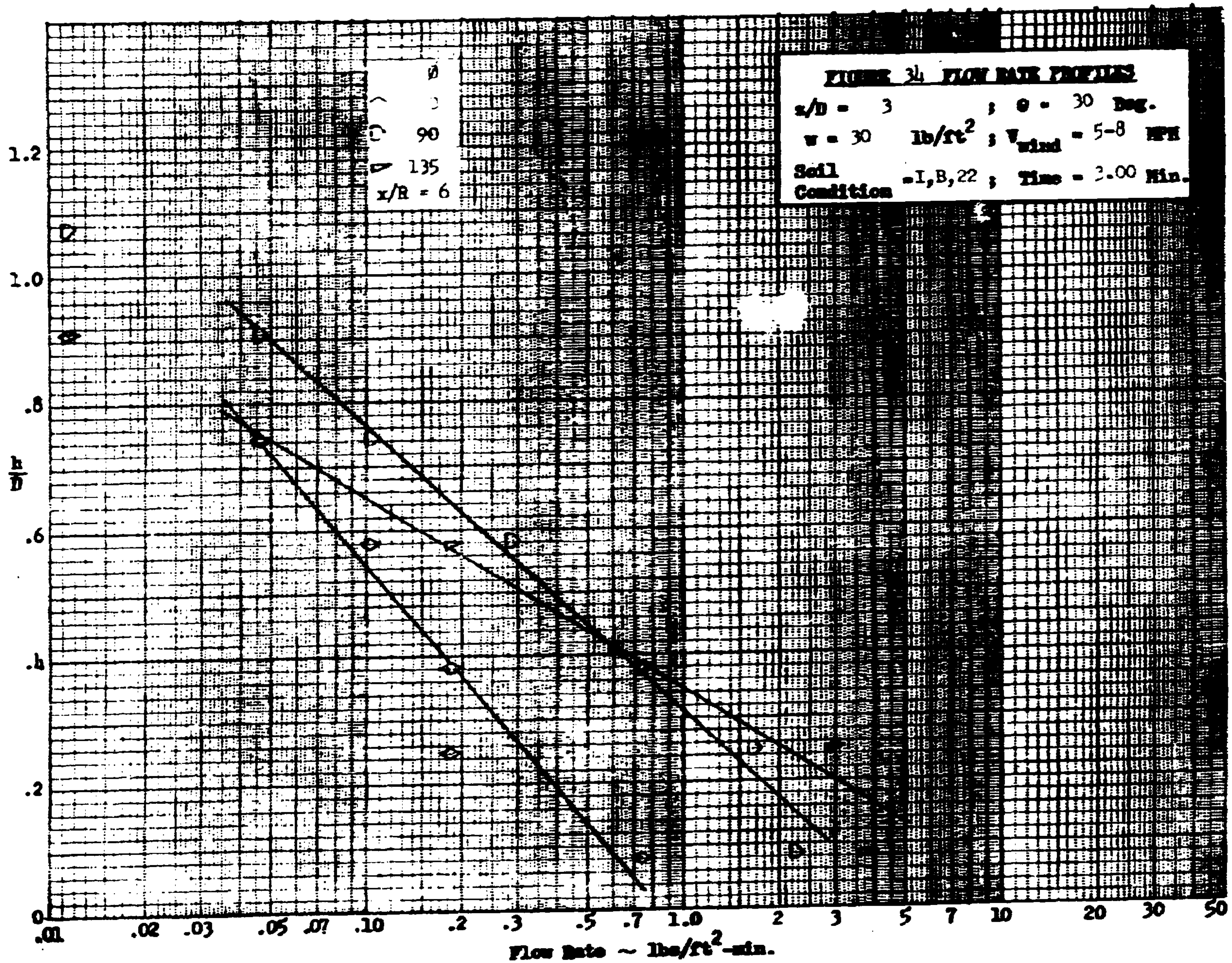


FIGURE 34 FLOW RATE PROFILES

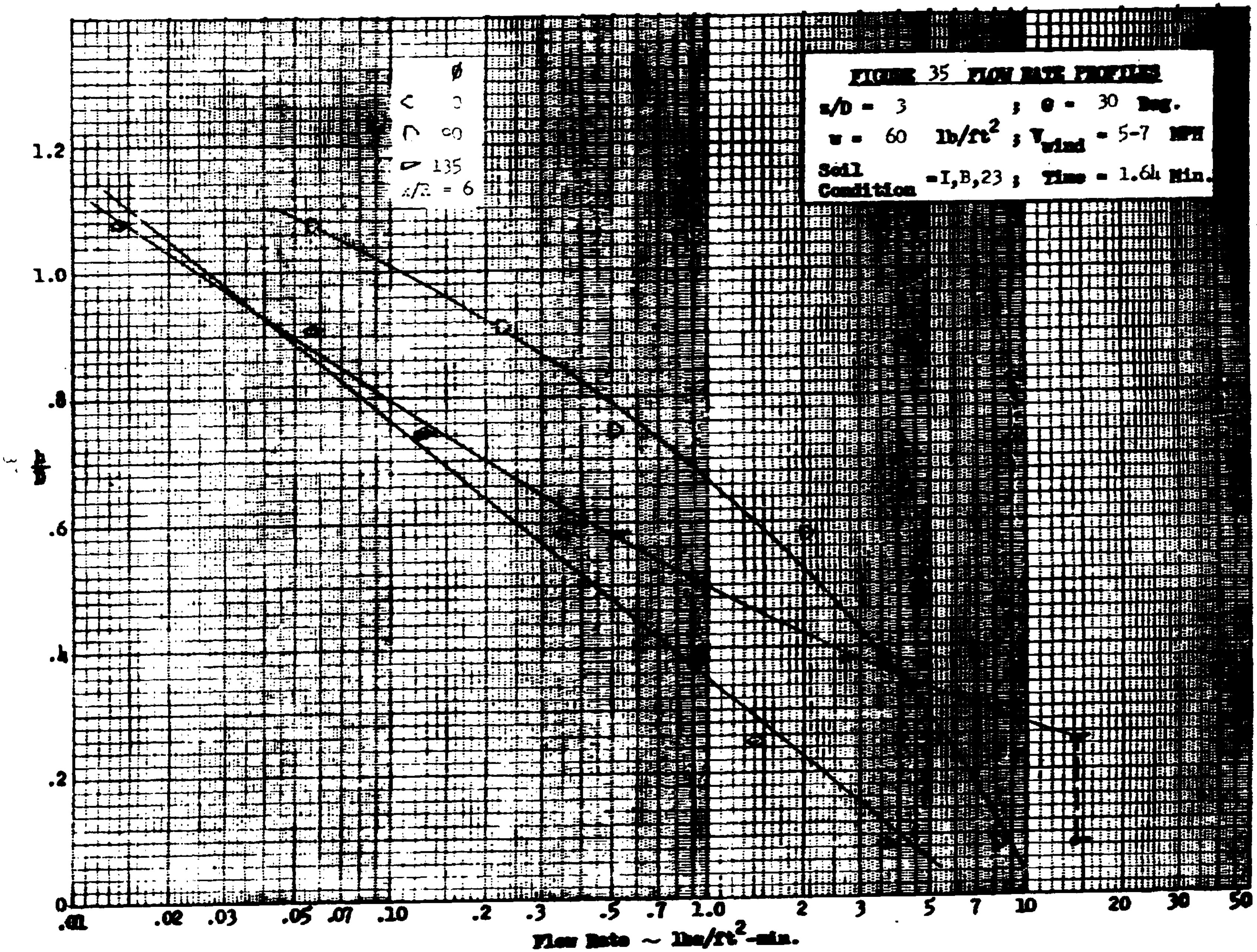


FIGURE 35 FLOW RATE PROFILES
x/D = 3 ; θ = 30 Deg.
w = 60 lb/ft² ; V_wind = 5-7 MPH
Soil Condition = I,B,23 ; Time = 1.64 Min.
ø
0
90
135
z/D = 6
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

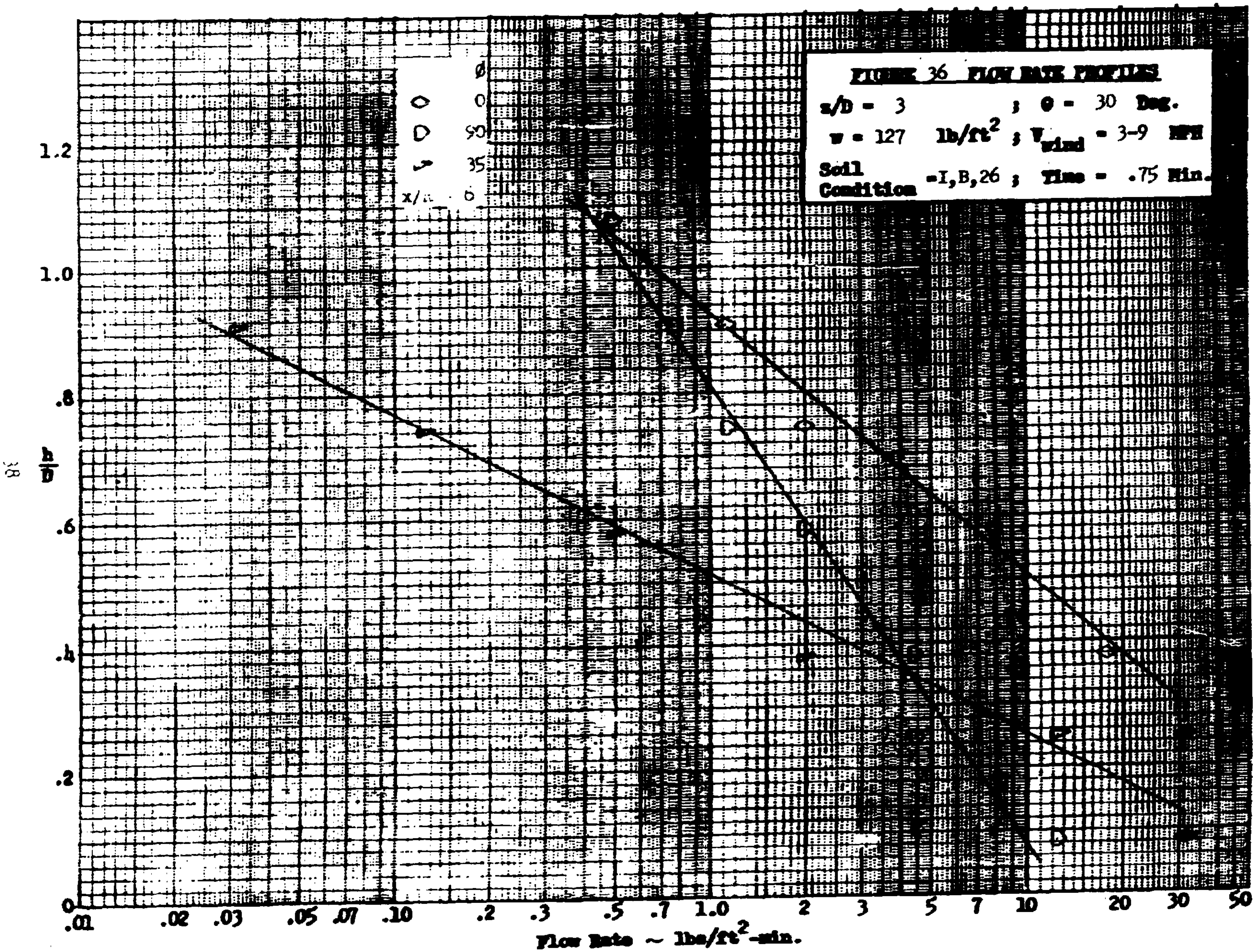


FIGURE 36 FLOW RATE PROFILES
x/D = 3 ; θ = 30 Deg.
w = 127 lb/ft² ; V wind = 3-9 MPH
Soil Condition = I,B,26 ; Time = .75 Min.
ø
0
90
35
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

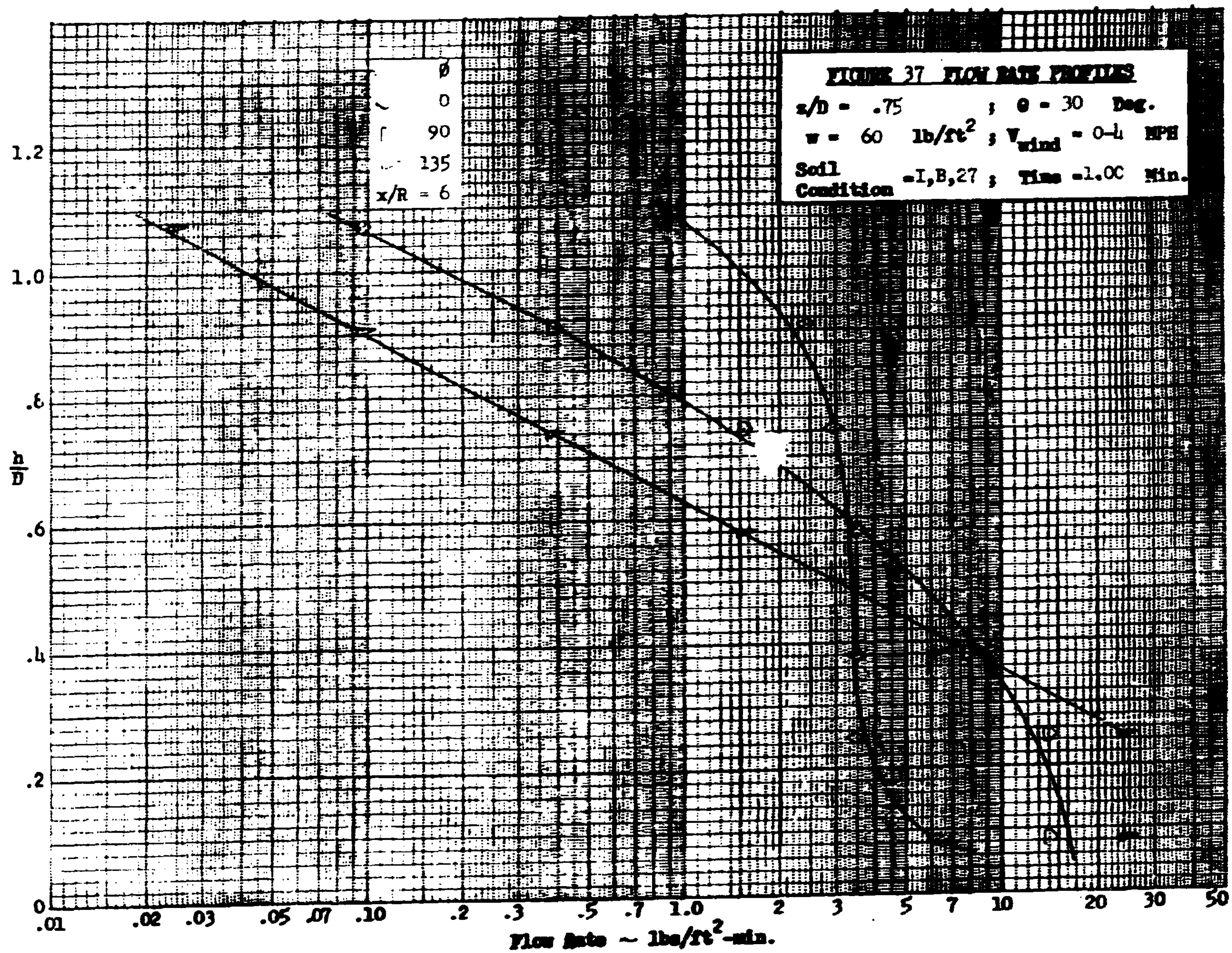


FIGURE 37 FLOW RATE PROFILES
x/D = .75 ; θ = 30 Deg.
w = 60 lb/ft² ; V wind = 0-4 MPH
Soil Condition =I,B,27 ; Time =1.00 Min.
ø
0
90
135
x/R = 6
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

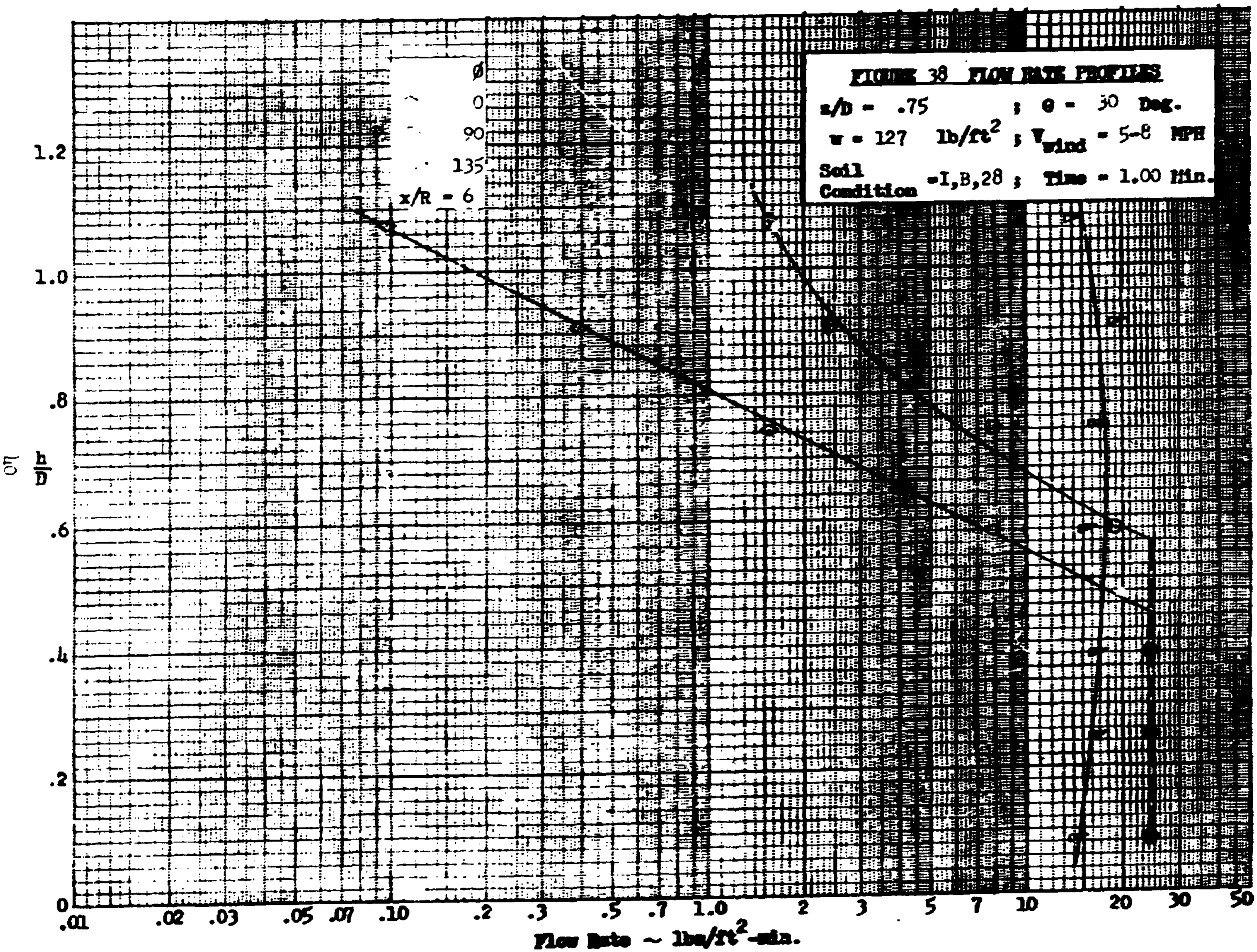


FIGURE 38 FLOW RATE PROFILES
z/D = .75 ; θ = 30 Deg.
w = 127 lb/ft^2 ; V$_{wind}$ = 5-8 MPH
Soil Condition = I,B,28 ; Time = 1.00 Min.
ø
0
90
135
x/R = 6
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbm/ft^2-min.

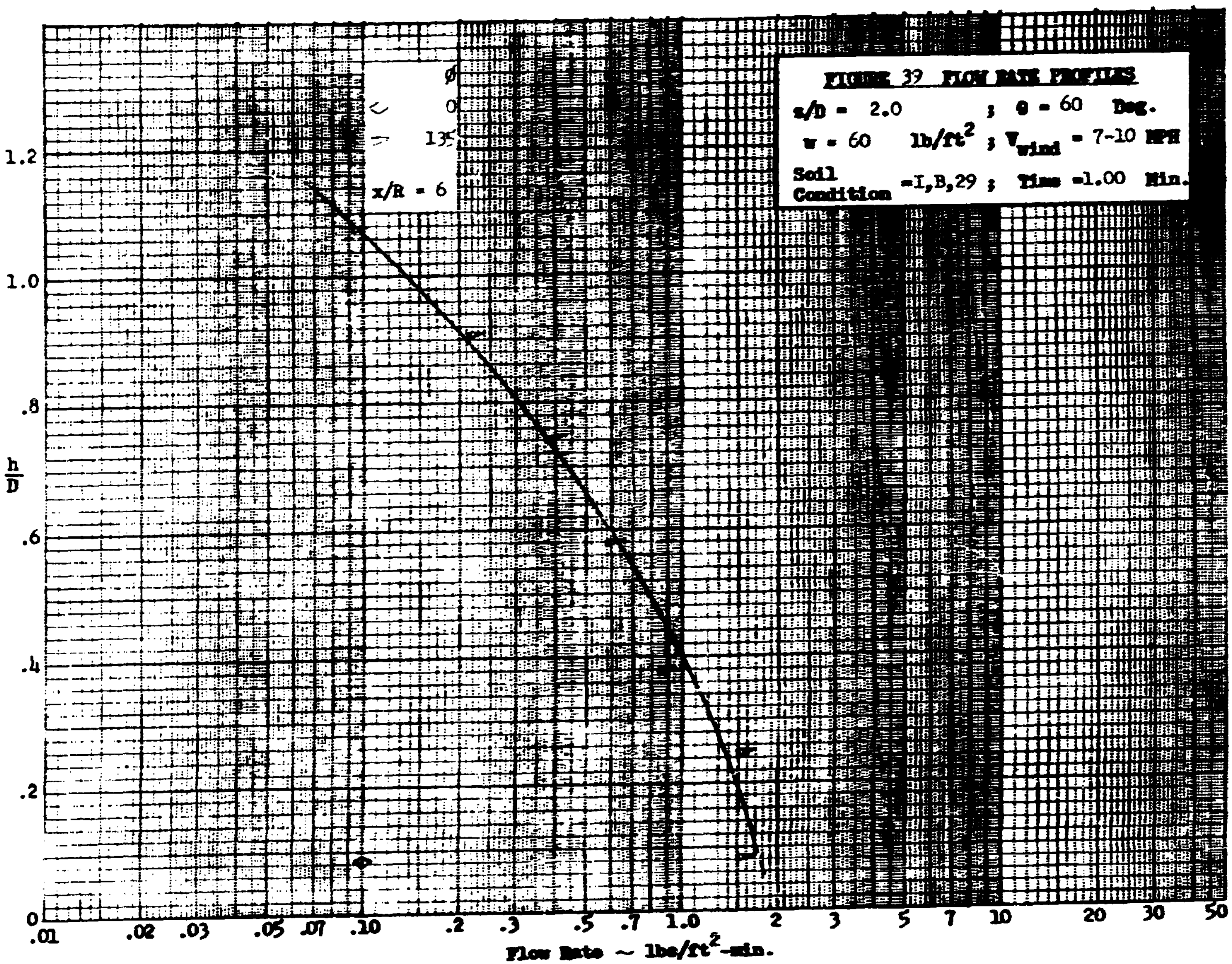


FIGURE 39 FLOW RATE PROFILES
x/D = 2.0 ; θ = 60 Deg.
w = 60 lb/ft² ; V_wind = 7-10 MPH
Soil Condition =I,B,29 ; Time =1.00 Min.
ϕ
0
135
x/R = 6
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

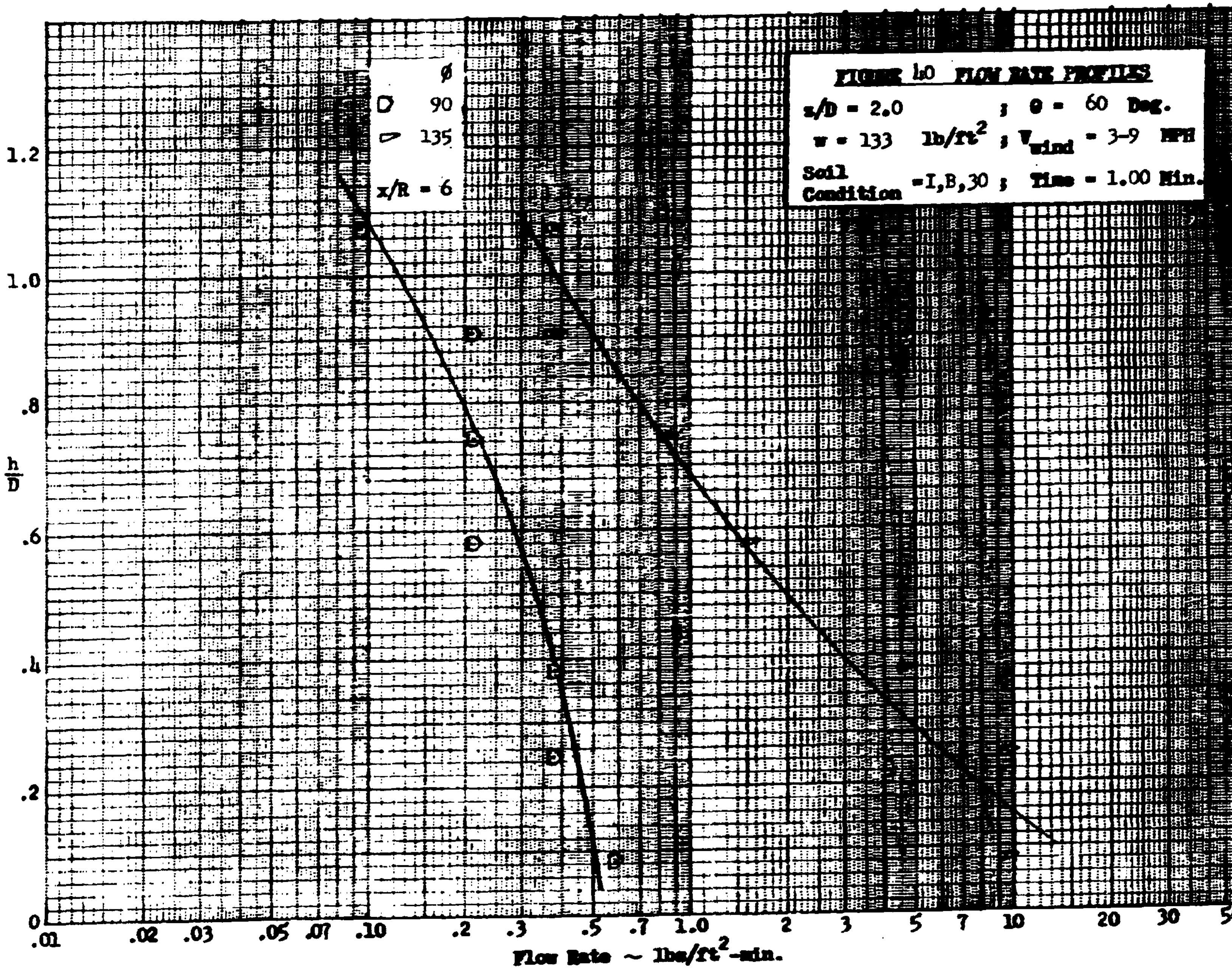
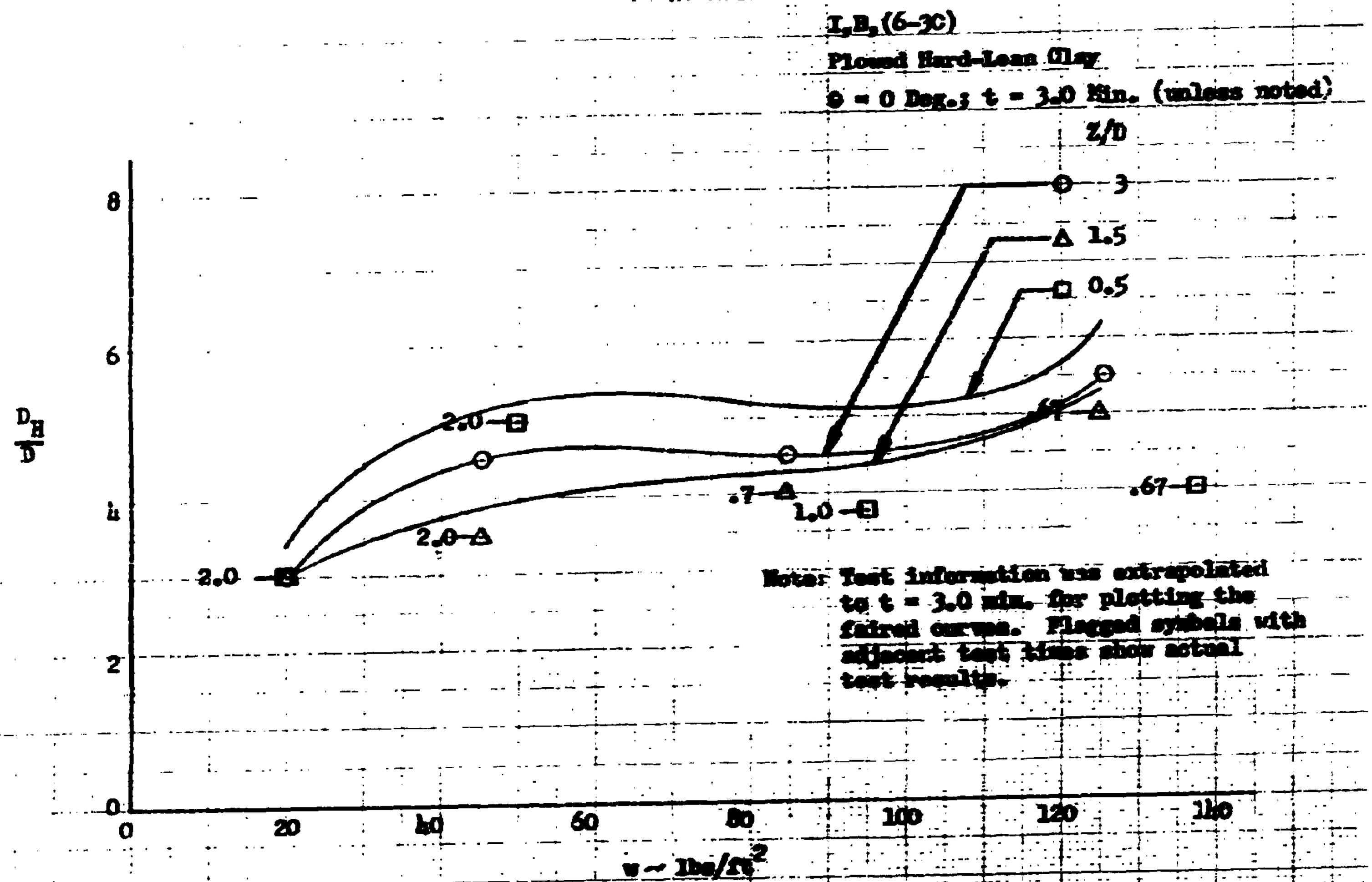


FIGURE 40 FLOW RATE PROFILES
x/D = 2.0 ; θ = 60 Deg.
w = 133 lb/ft² ; V wind = 3-9 MPH
Soil Condition = I,B,30 ; Time = 1.00 Min.
ø
90
135
x/R = 6
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

FIGURE 43 RELATIVE DIAMETER OF



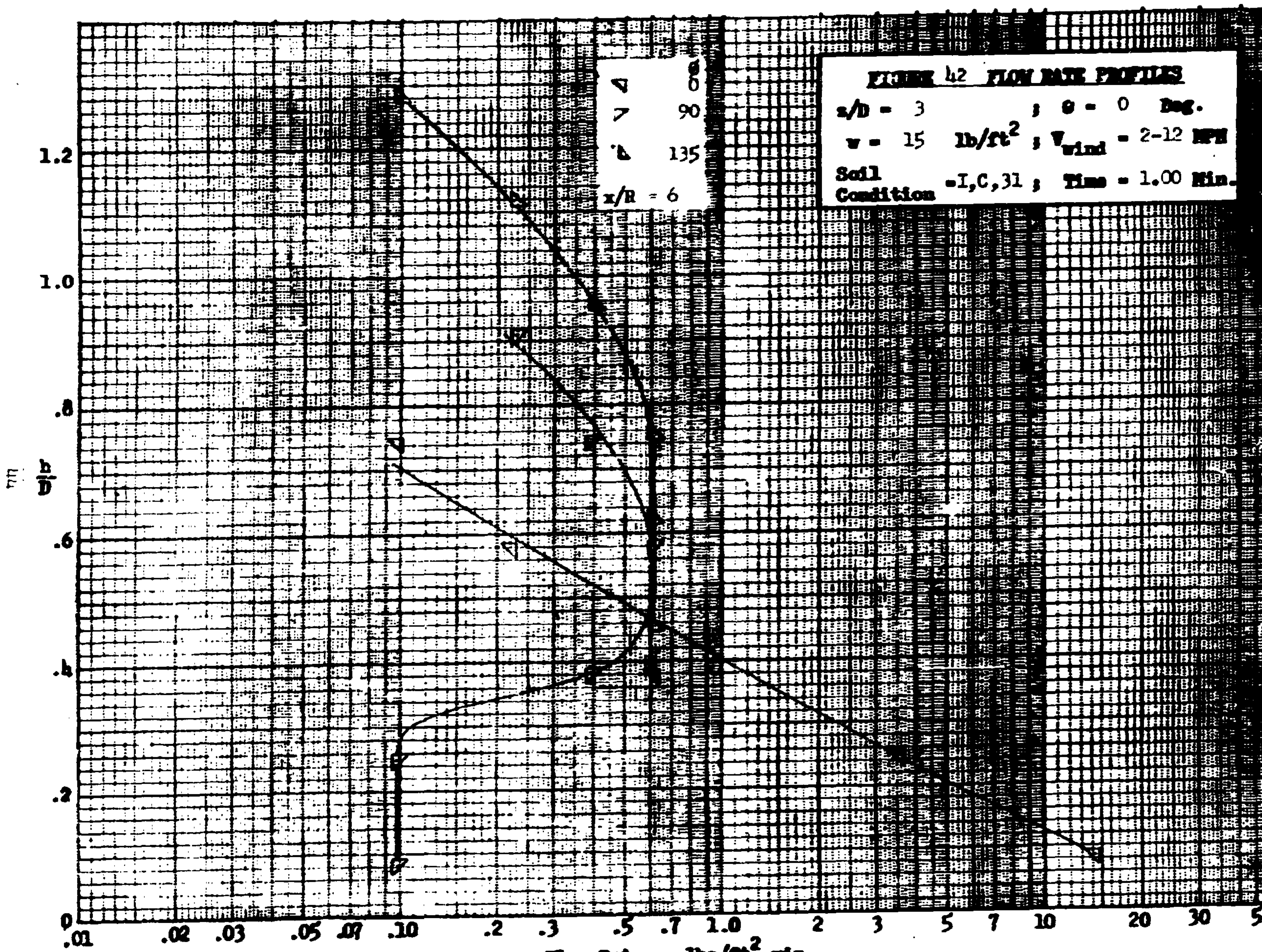


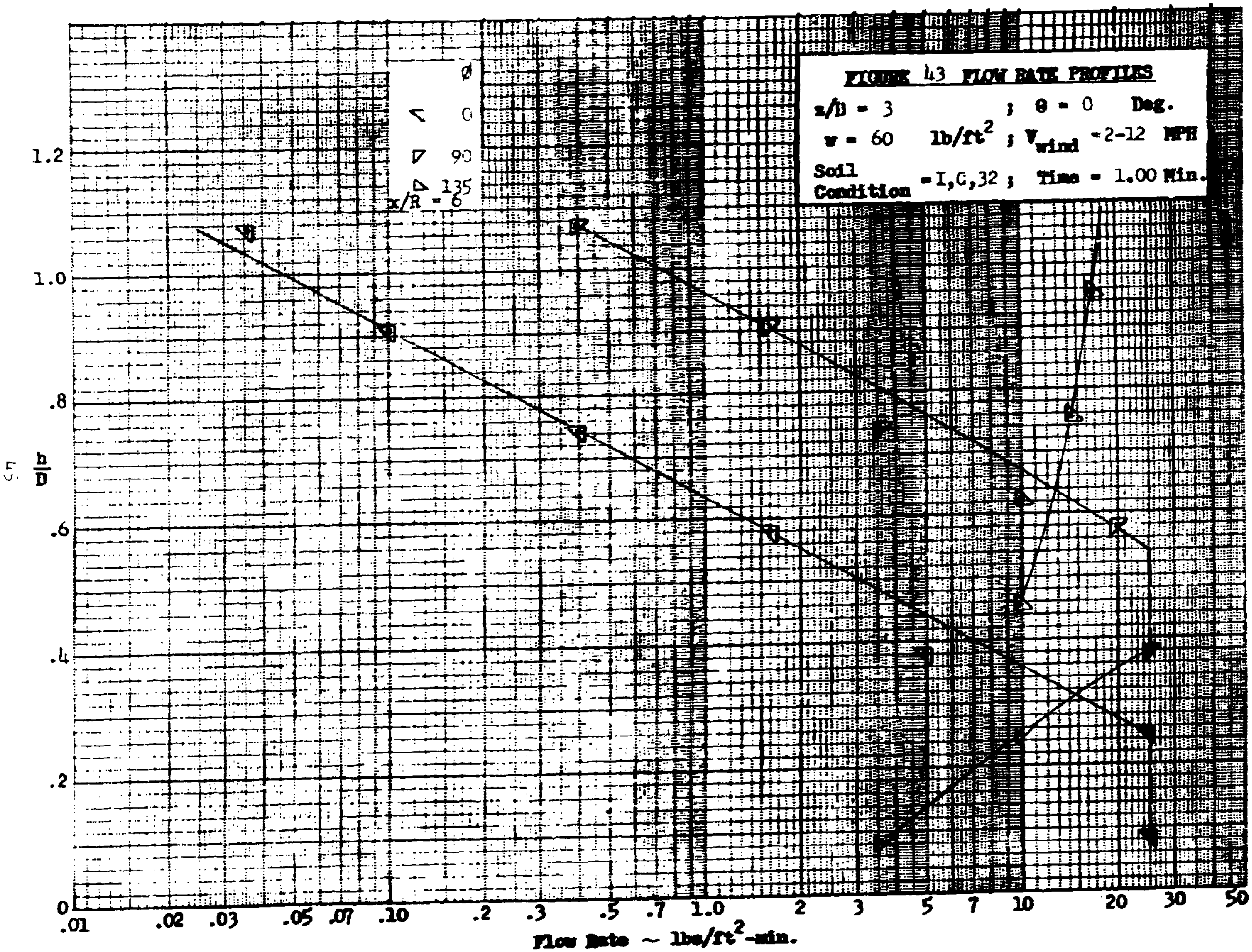
FIGURE 42 FLOW RATE PROFILES
z/D = 3 ; θ = 0 Deg.
w = 15 lb/ft² ; V wind = 2-12 MPH
Soil Condition =I,C,31 ; Time = 1.00 Min.
θ
0
90
135
x/R = 6
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

FIGURE 43 FLOW RATE PROFILES

z/D = 3 ; θ = 0 Deg.

w = 60 lb/ft^2 ; V_{wind} = 2-12 MPH

Soil Condition = I,G,32 ; Time = 1.00 Min.



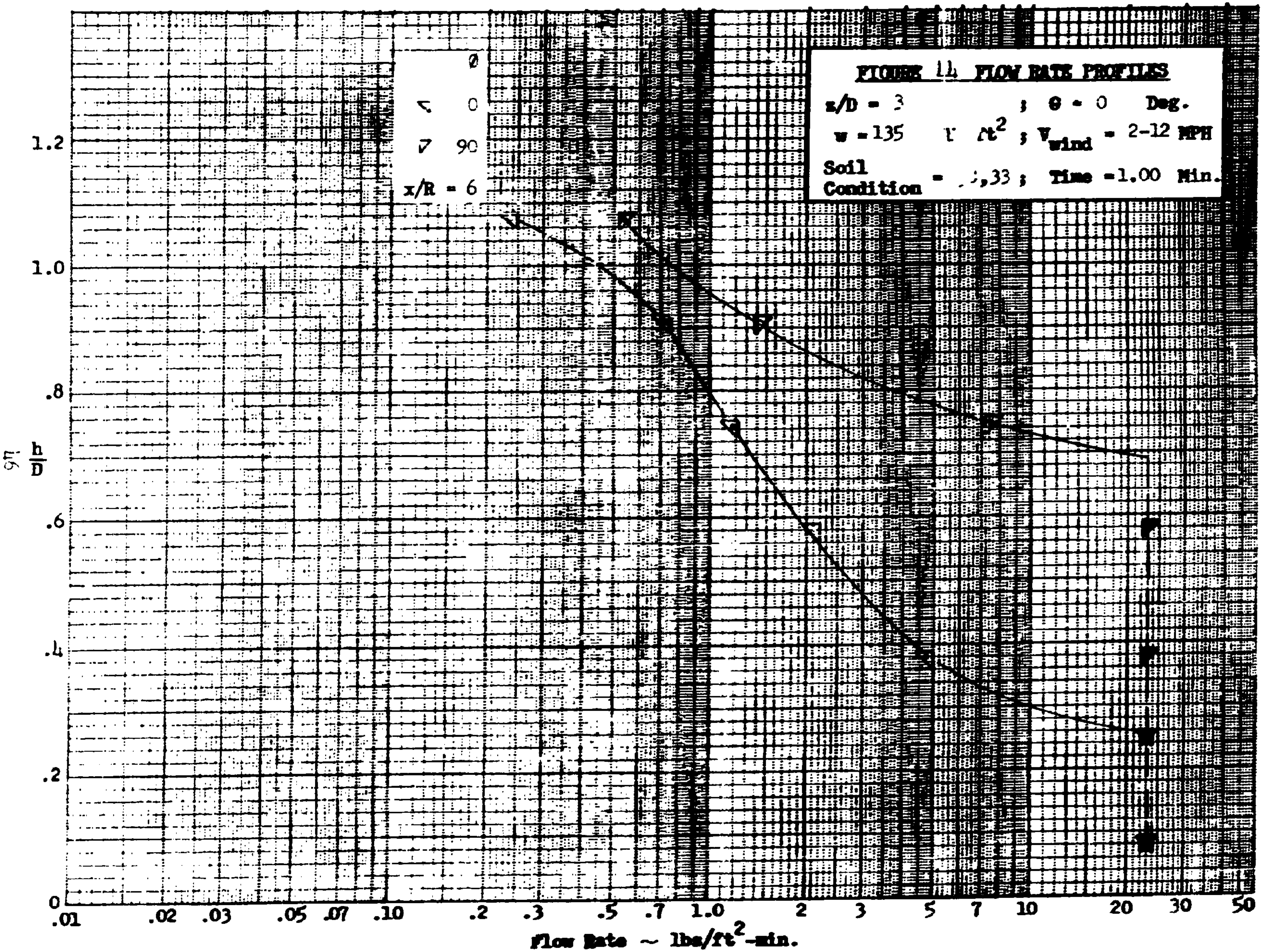


FIGURE 14 FLOW RATE PROFILES
x/D = 3 ; θ = 0 Deg.
w = 135 ft² ; V_wind = 2-12 MPH
Soil Condition = .33 ; Time = 1.00 Min.
ø
0
90
x/R = 6
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

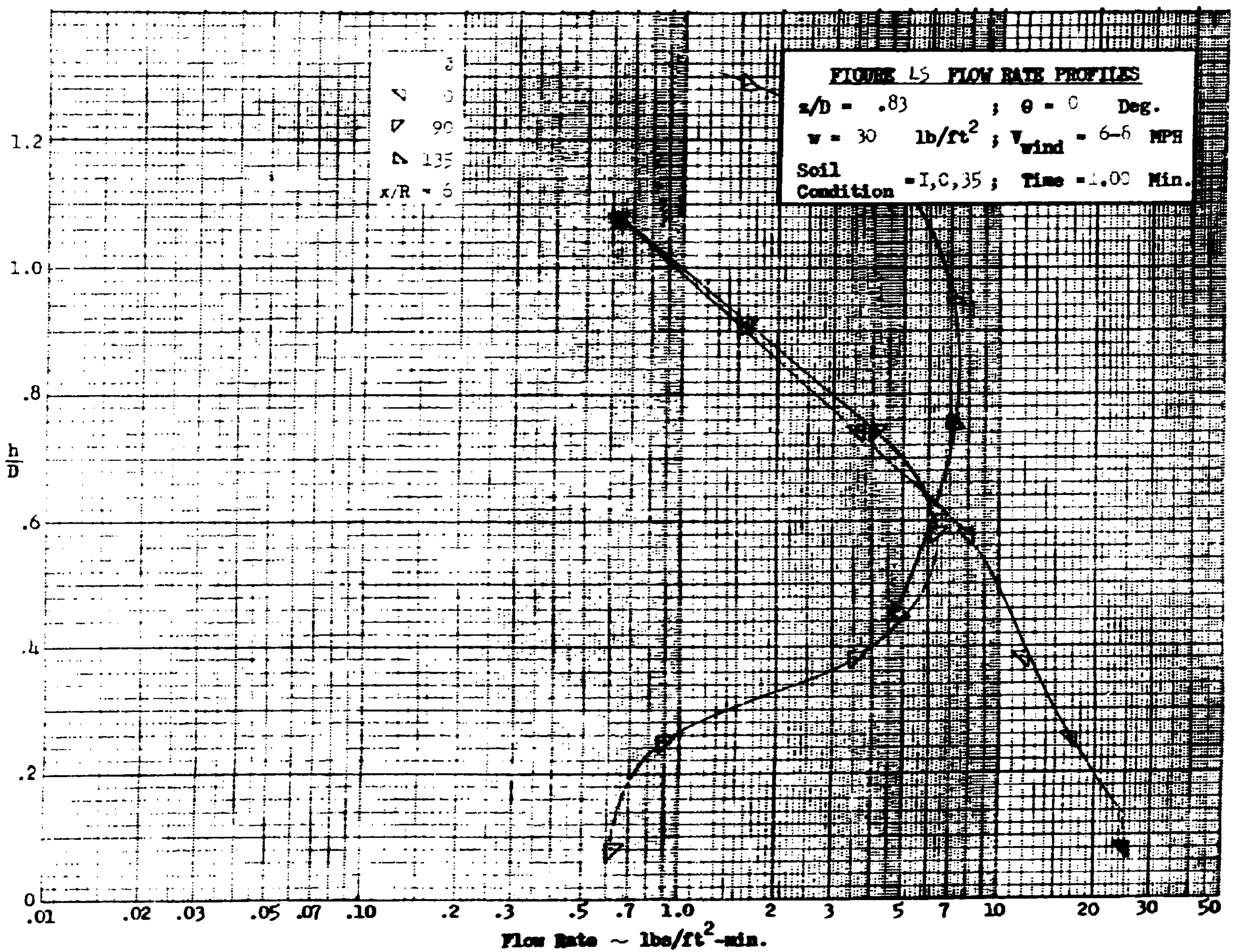


FIGURE 45 FLOW RATE PROFILES
z/D = .83 ; θ = 0 Deg.
w = 30 lb/ft² ; V wind = 6-6 MPH
Soil Condition = I,C,35 ; Time = 1.00 Min.
θ
0
90
135
x/R = 6
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

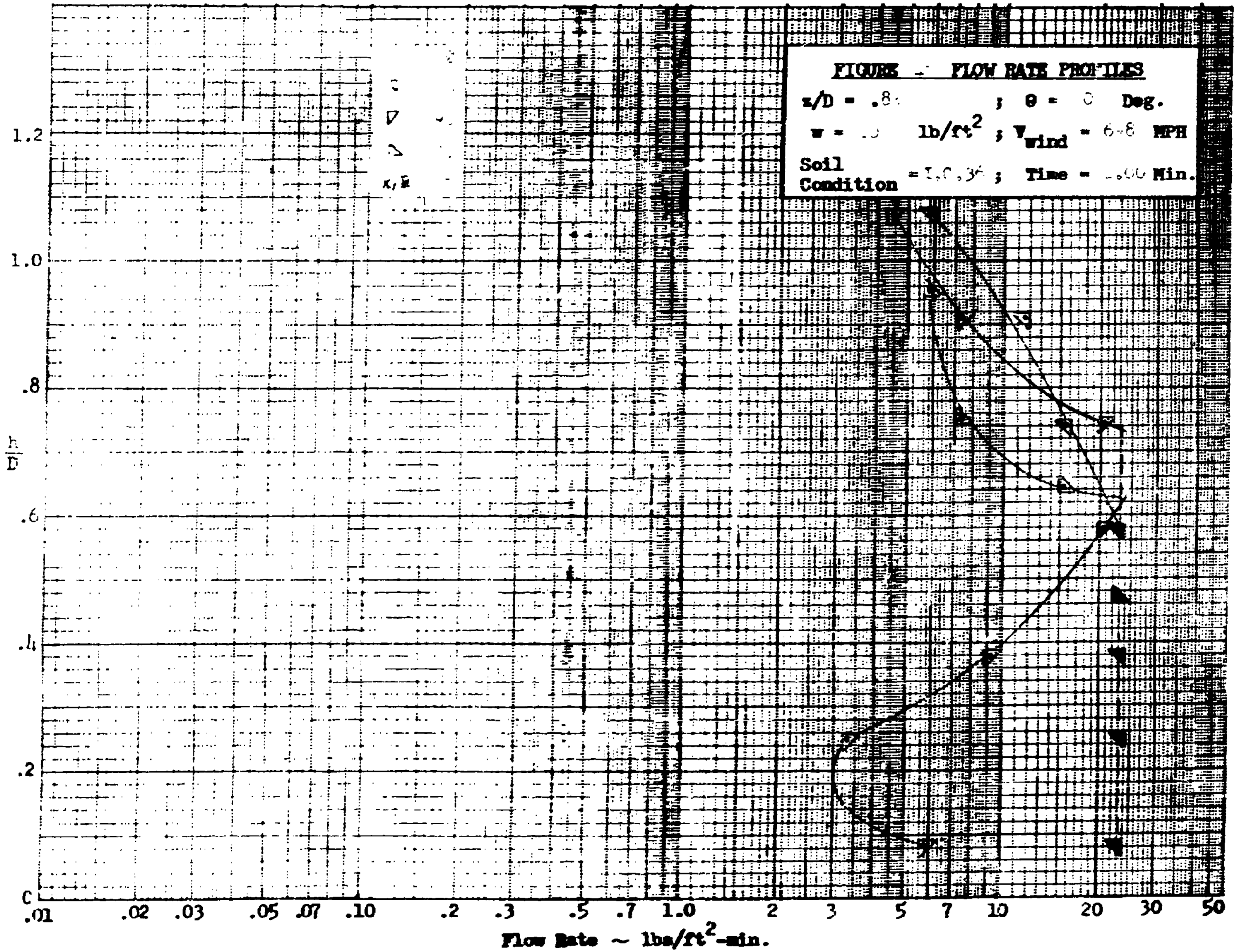


FIGURE - FLOW RATE PROFILES
z/D = .8 ; θ = 0 Deg.
w = lb/ft² ; V wind = 6-8 MPH
Soil Condition ; Time = Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

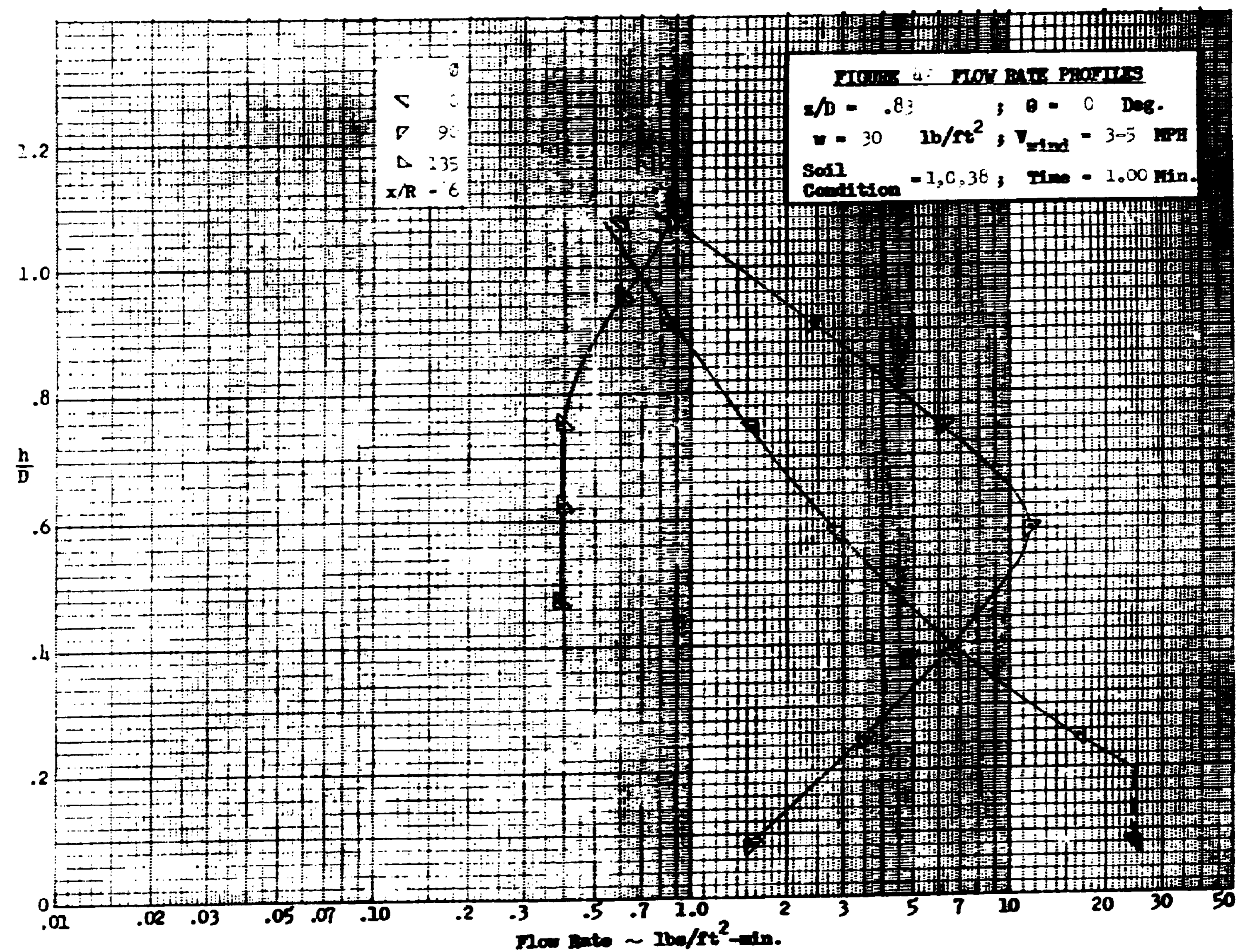


FIGURE 4? FLOW RATE PROFILES
z/D = .83 ; θ = 0 Deg.
w = 30 lb/ft² ; V_wind = 3-5 MPH
Soil Condition = 1,C,38 ; Time = 1.00 Min.
θ
0
90
135
x/R = 6
h/D
0
.2
.4
.6
.8
1.0
1.2
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

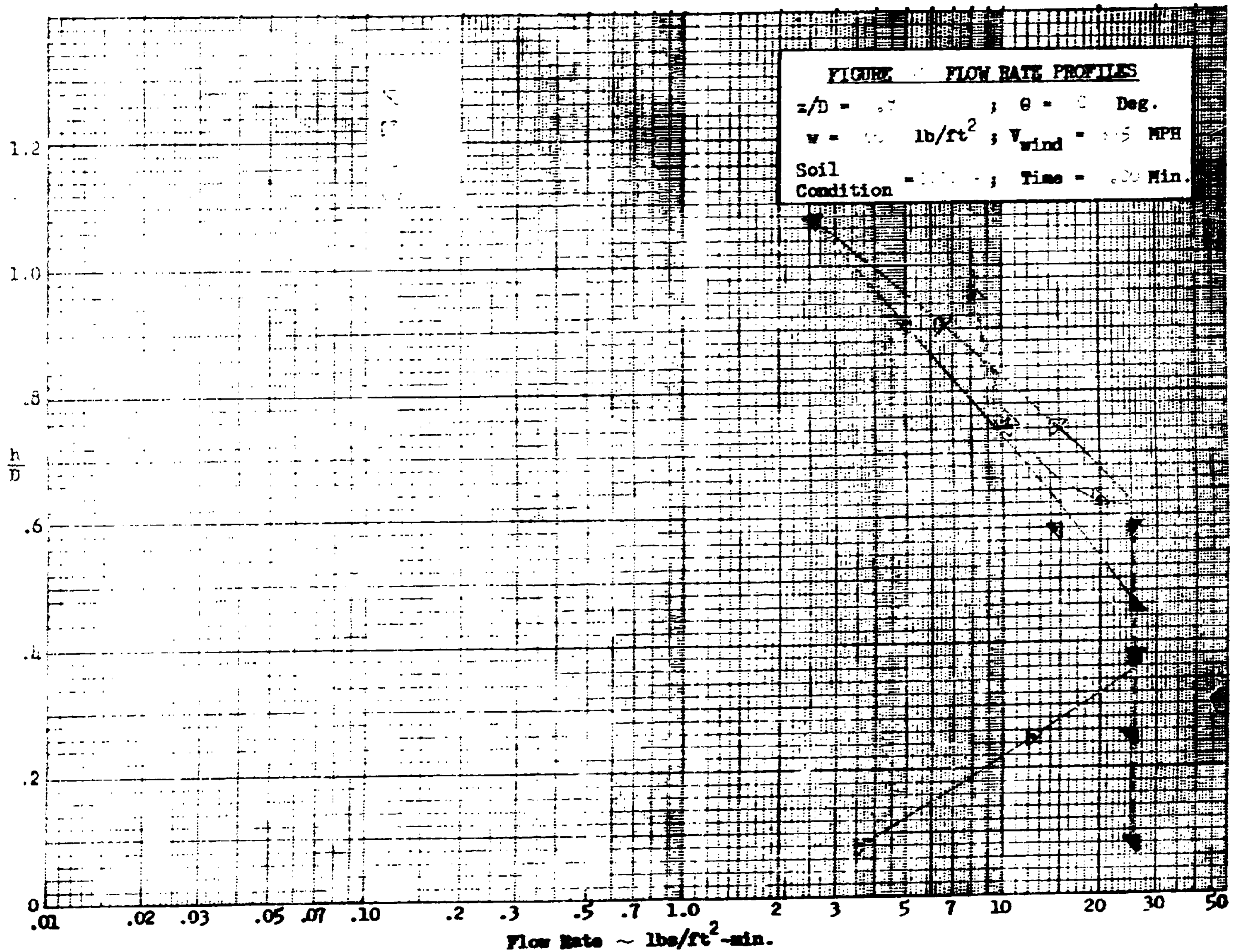
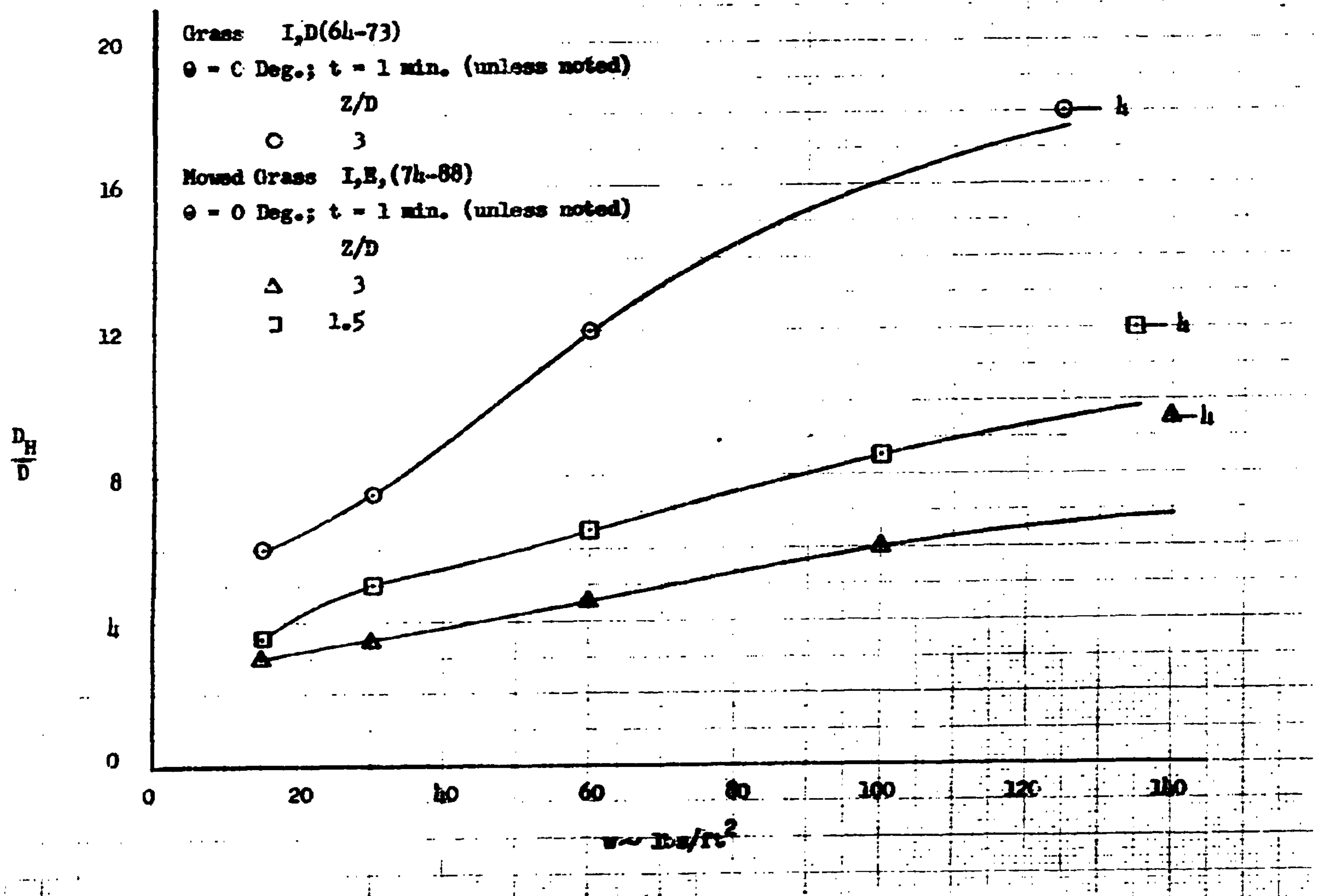


FIGURE FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft² ; V wind = MPH
Soil Condition = ; Time = Min.
1.2
1.0
.8
h/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

FIGURE 49 RELATIVE DIAMETER OF INFLUENCED SECTION



F-12D

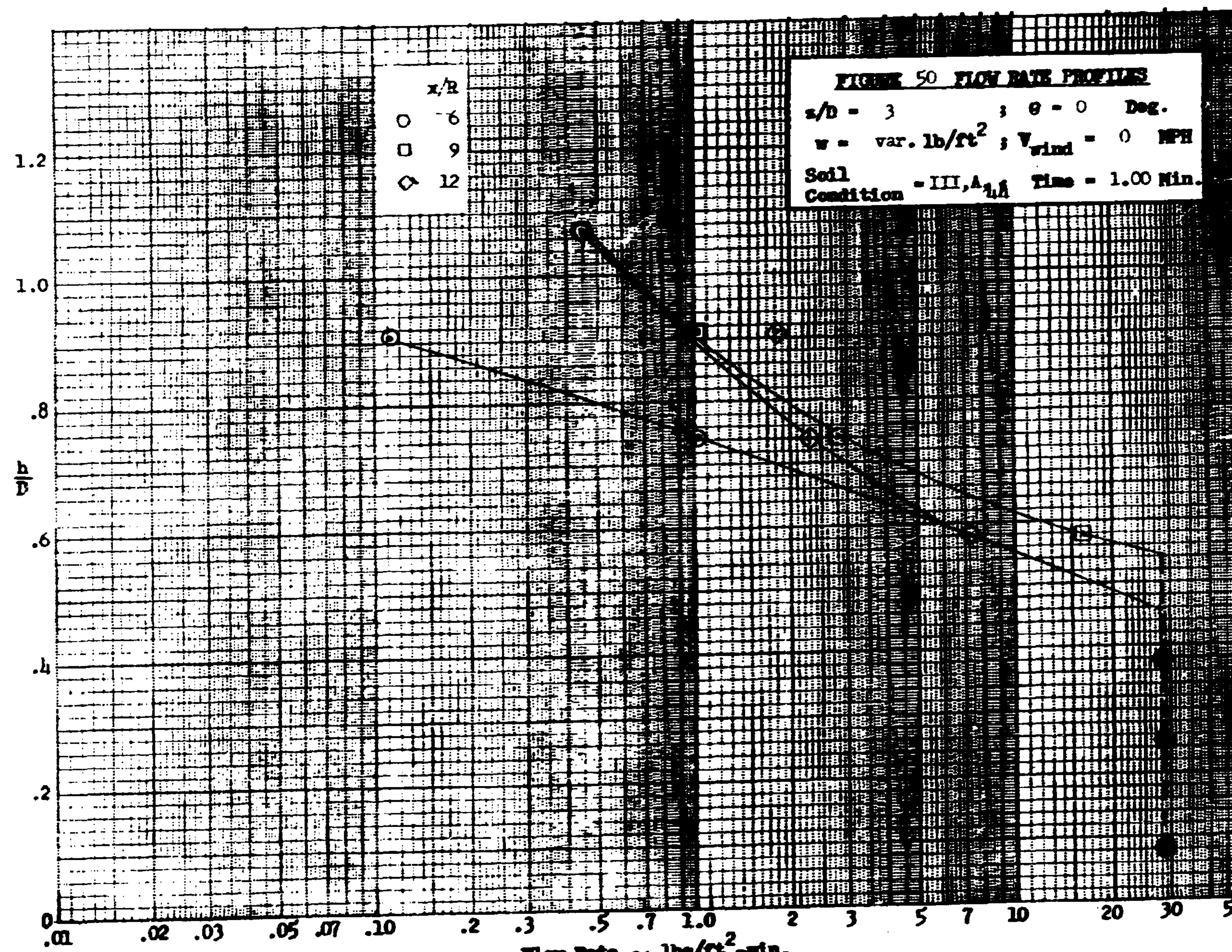


FIGURE 50 FLOW RATE PROFILES
z/D = 3 ; θ = 0 Deg.
w = var. lb/ft² ; V wind = 0 MPH
Soil Condition = III, A 44 Time = 1.00 Min.
x/R
○ 6
□ 9
◇ 12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

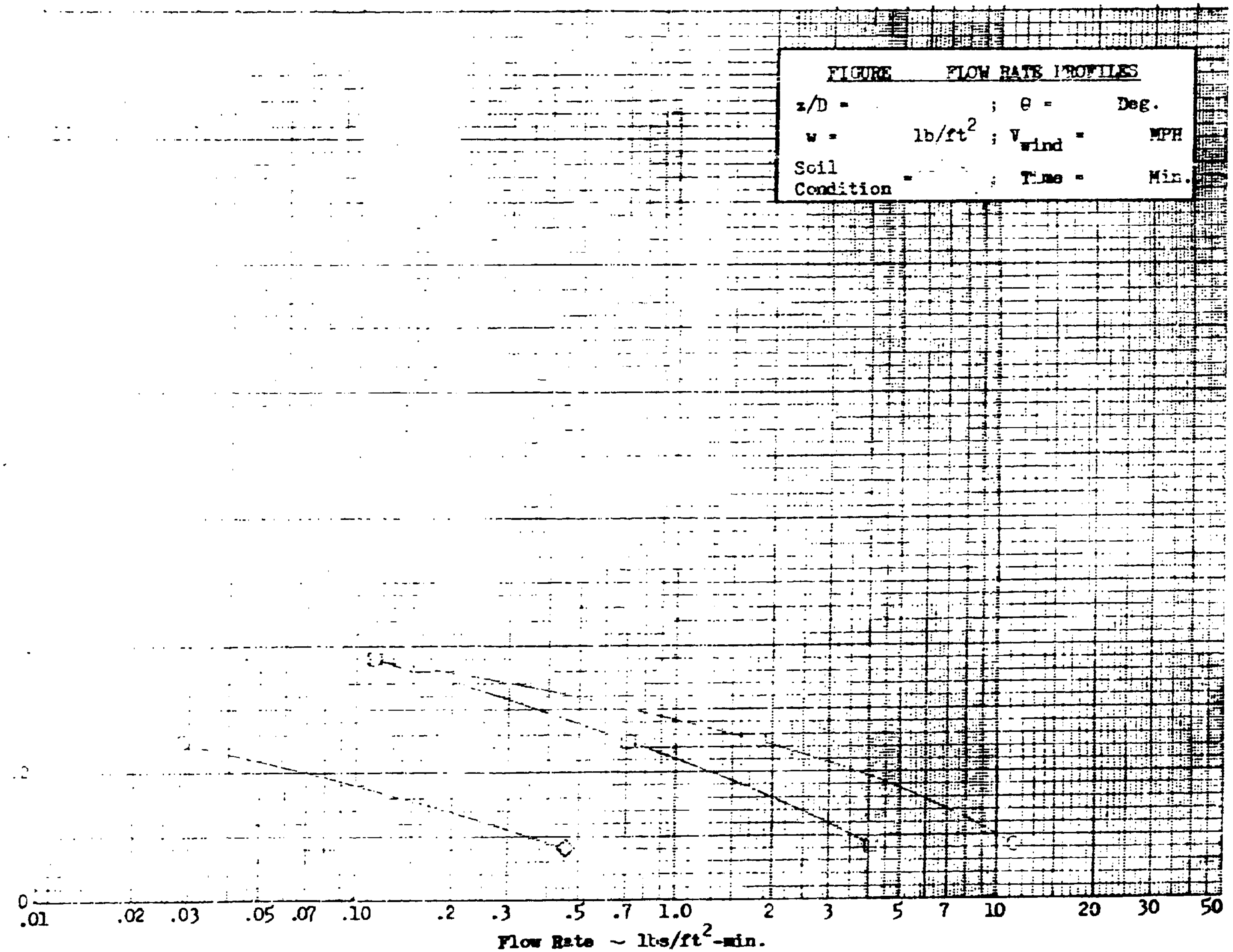


FIGURE FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft^2 ; V_{wind} = MPH
Soil Condition = ; Time = Min.
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

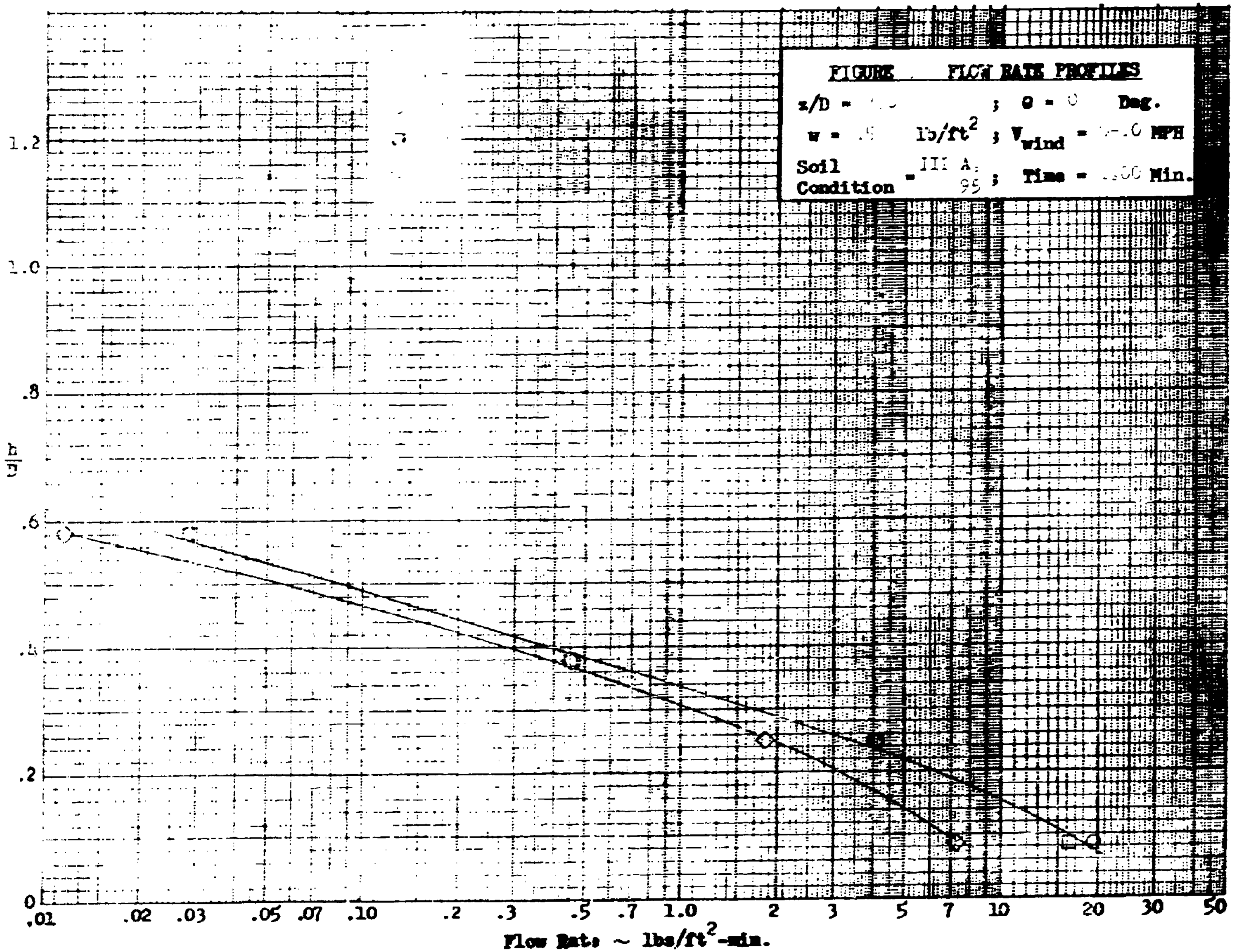


FIGURE FLOW RATE PROFILES
z/D = ; θ = 0 Deg.
w = lb/ft²; V wind = MPH
Soil Condition = III A; 95 ; Time = Min.
1.2
1.0
.8
.6
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

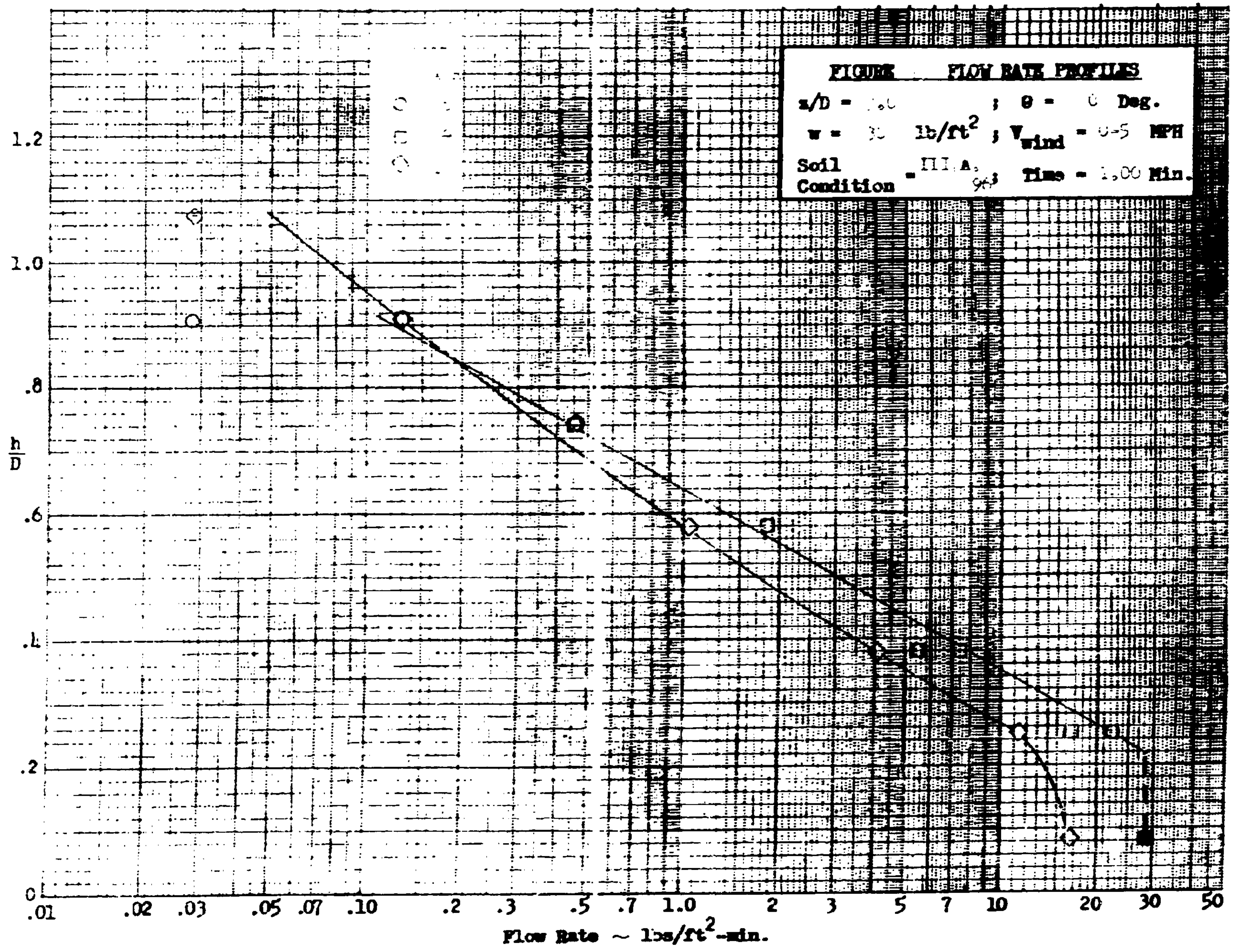


FIGURE FLOW RATE PROFILES
x/D = ; θ = 0 Deg.
w = lb/ft²; V_wind = 0-5 MPH
Soil Condition = III A; Time = 1.00 Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

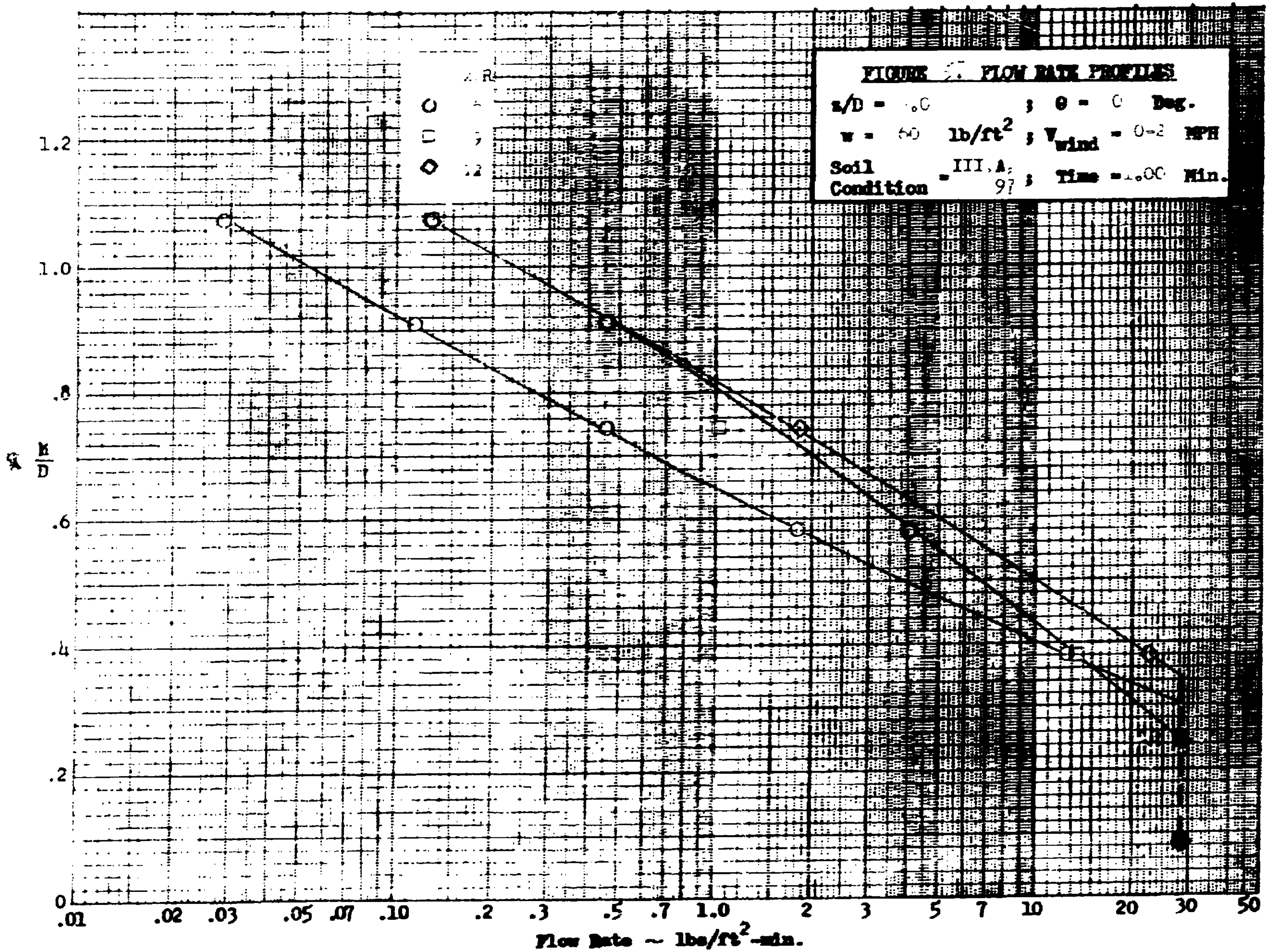


FIGURE . FLOW RATE PROFILES
z/D = .0 ; θ = 0 Deg.
w = 60 lb/ft² ; V_wind = 0-2 MPH
Soil Condition = III, A, 97 ; Time = 1.00 Min.
1.2
1.0
.8
.6
.4
.2
0
k/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

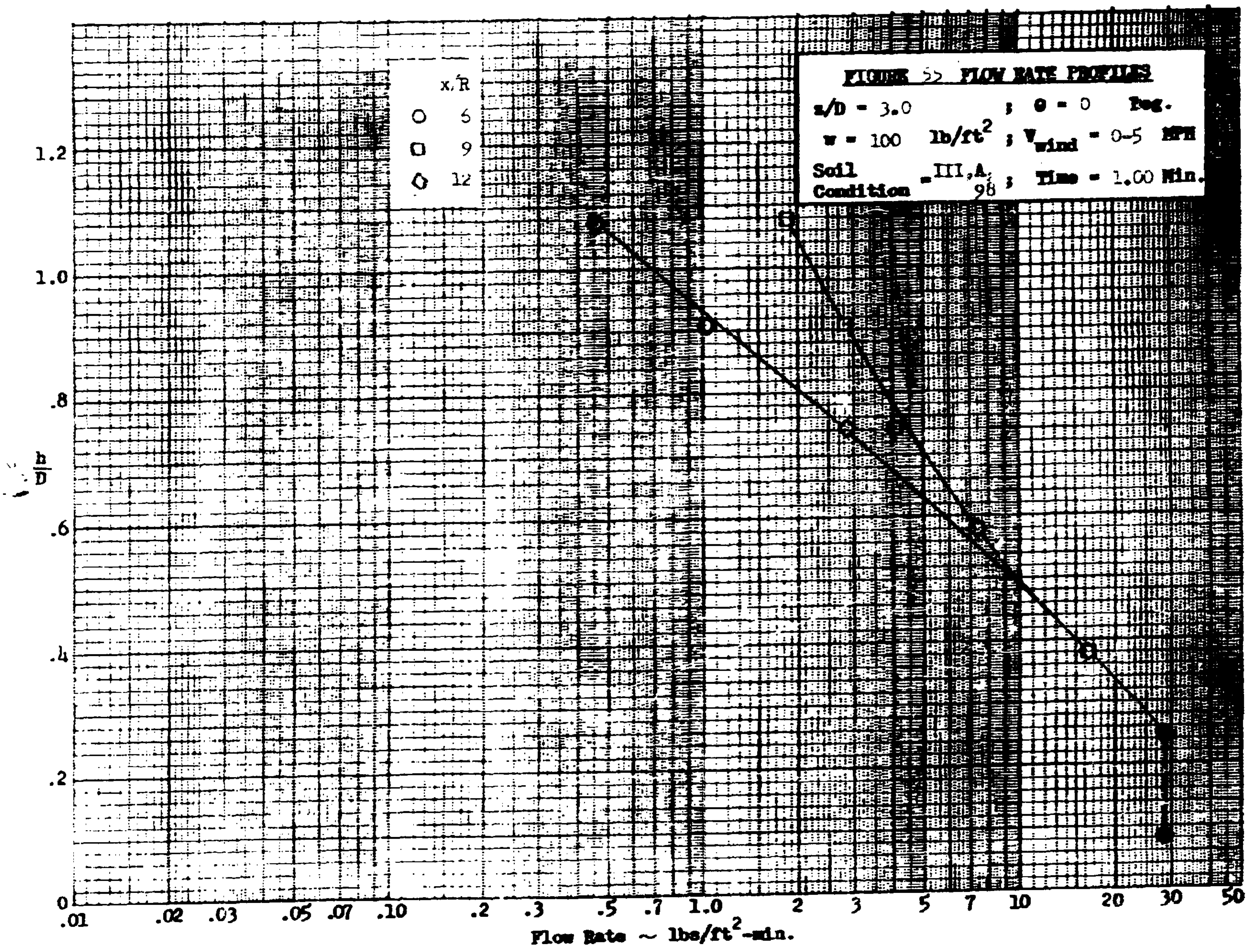


FIGURE 55 FLOW RATE PROFILES
x/D = 3.0 ; θ = 0 Deg.
w = 100 lb/ft² ; V_wind = 0-5 MPH
Soil Condition = III,A,98 ; Time = 1.00 Min.
x,R
6
9
12
1.2
1.0
.8
h/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

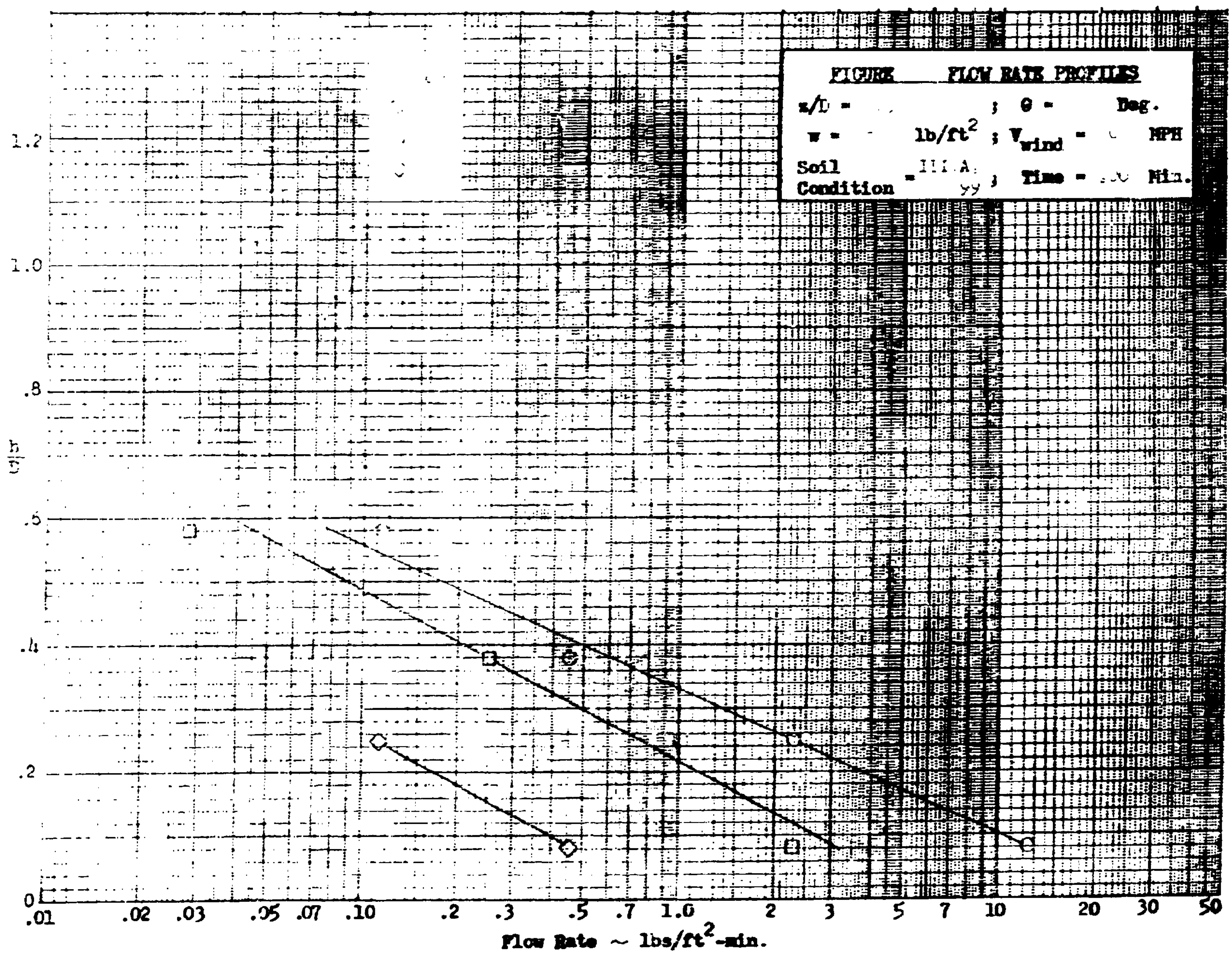


FIGURE FLOW RATE PROFILES
x/D = ; θ = Deg.
w = lb/ft²; V wind = MPH
Soil Condition = ; Time = Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

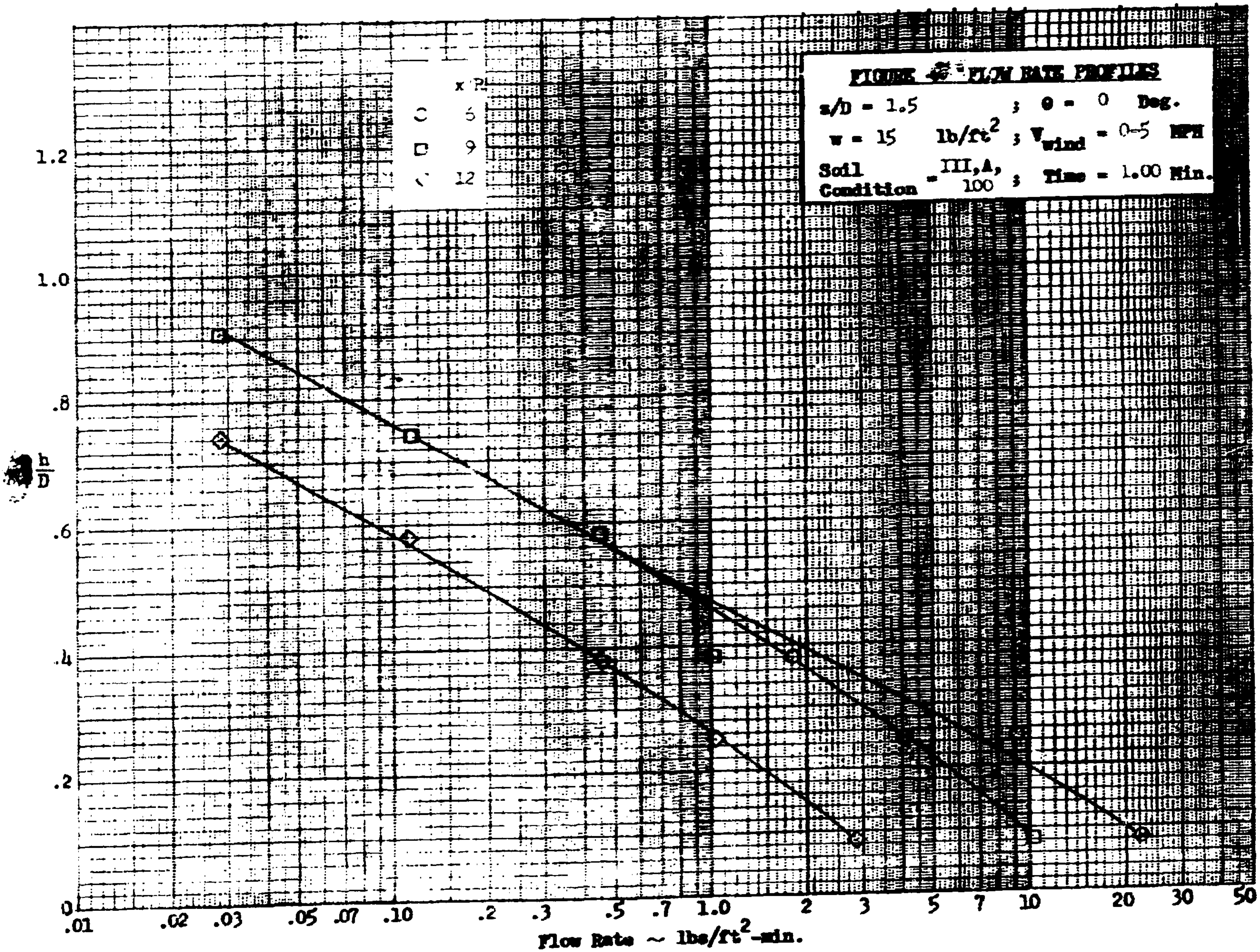


FIGURE - FLOW RATE PROFILES
s/D = 1.5 ; θ = 0 Deg.
w = 15 lb/ft² ; V wind = 0-5 MPH
Soil Condition = III,A,100 ; Time = 1.00 Min.
x P
6
9
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

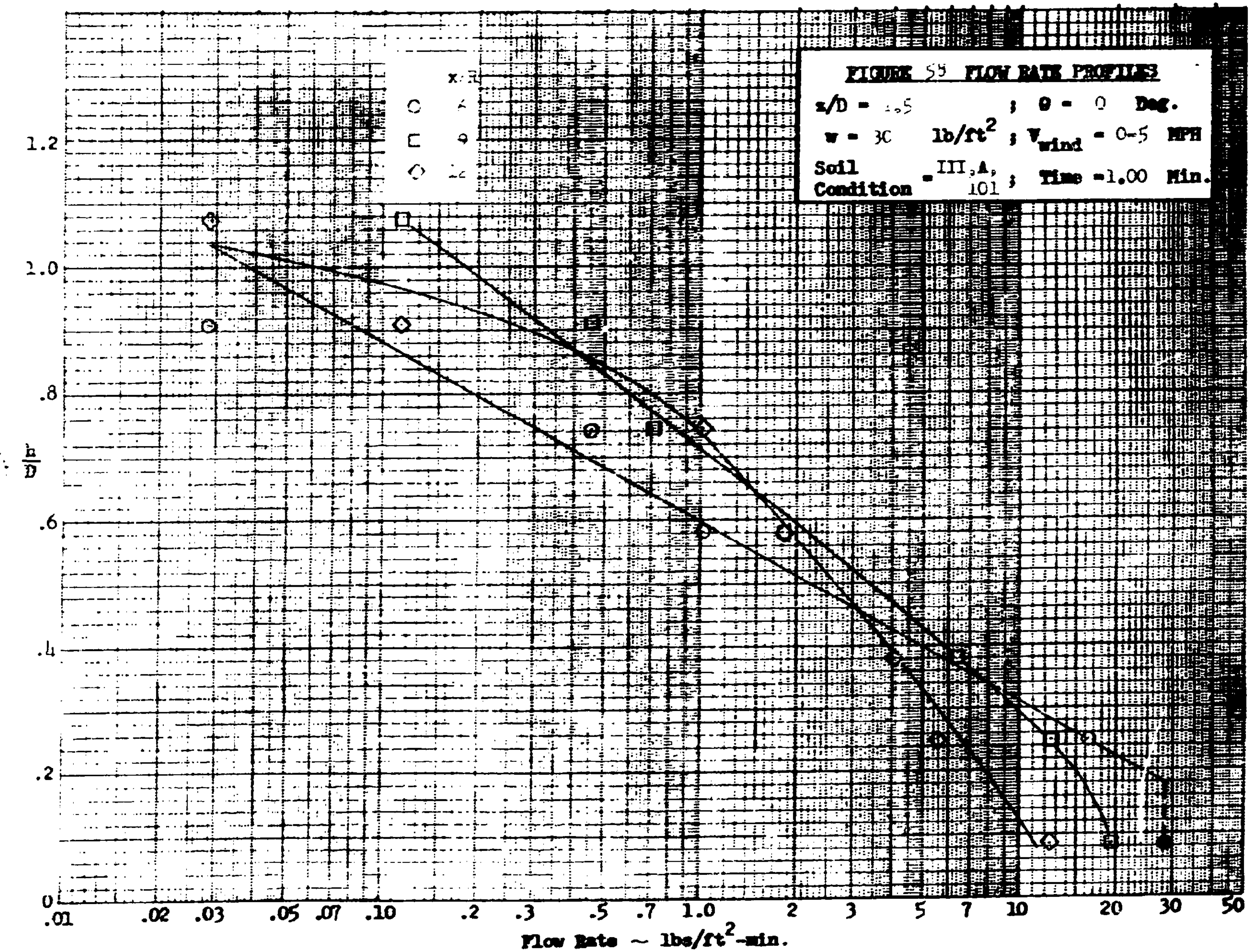


FIGURE 55 FLOW RATE PROFILES
x/D = 1.5 ; θ = 0 Deg.
w = 30 lb/ft² ; V wind = 0-5 MPH
Soil Condition = III, A, 101 ; Time = 1.00 Min.
x:R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

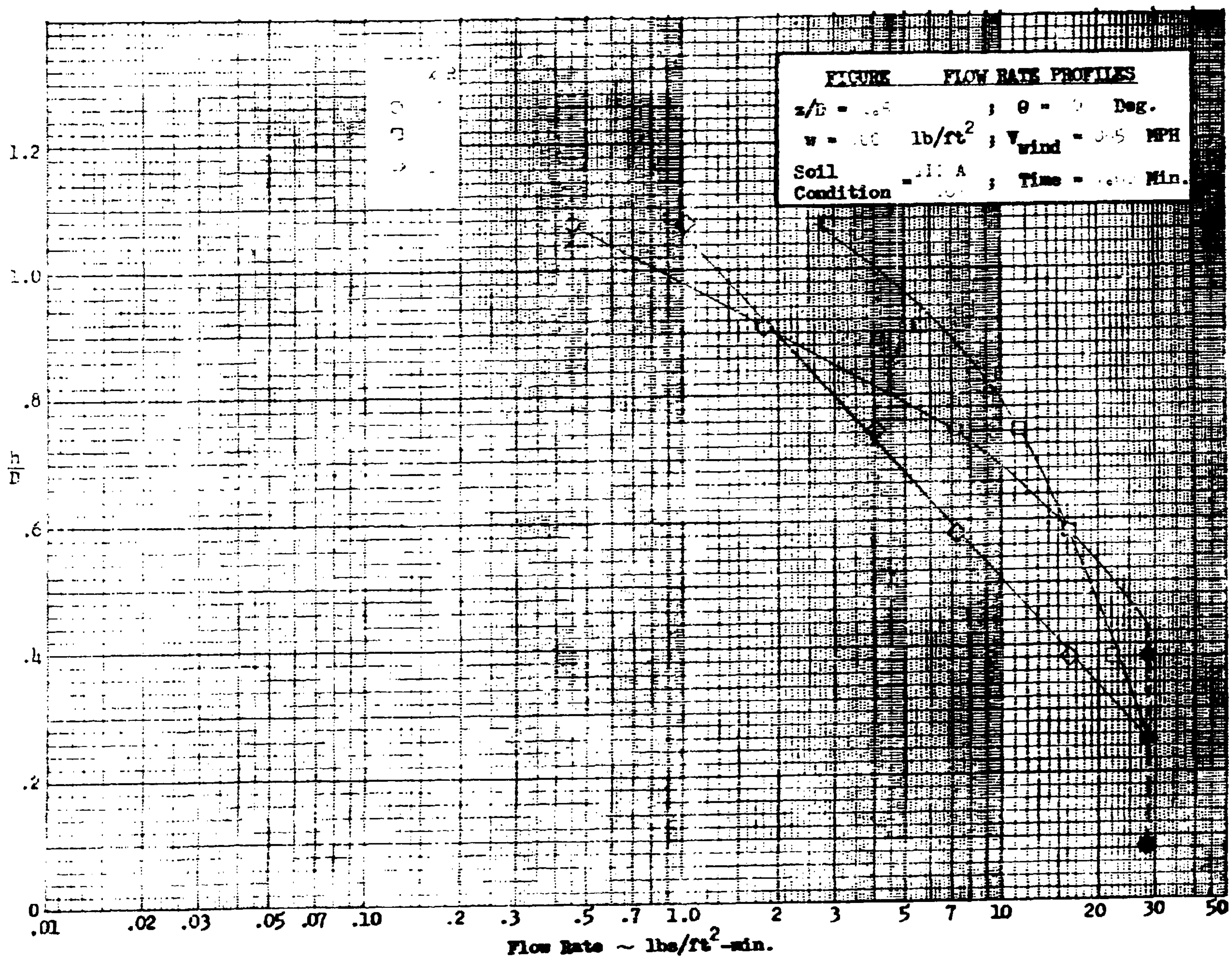


FIGURE FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft²; V_wind = MPH
Soil Condition = ; Time = Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

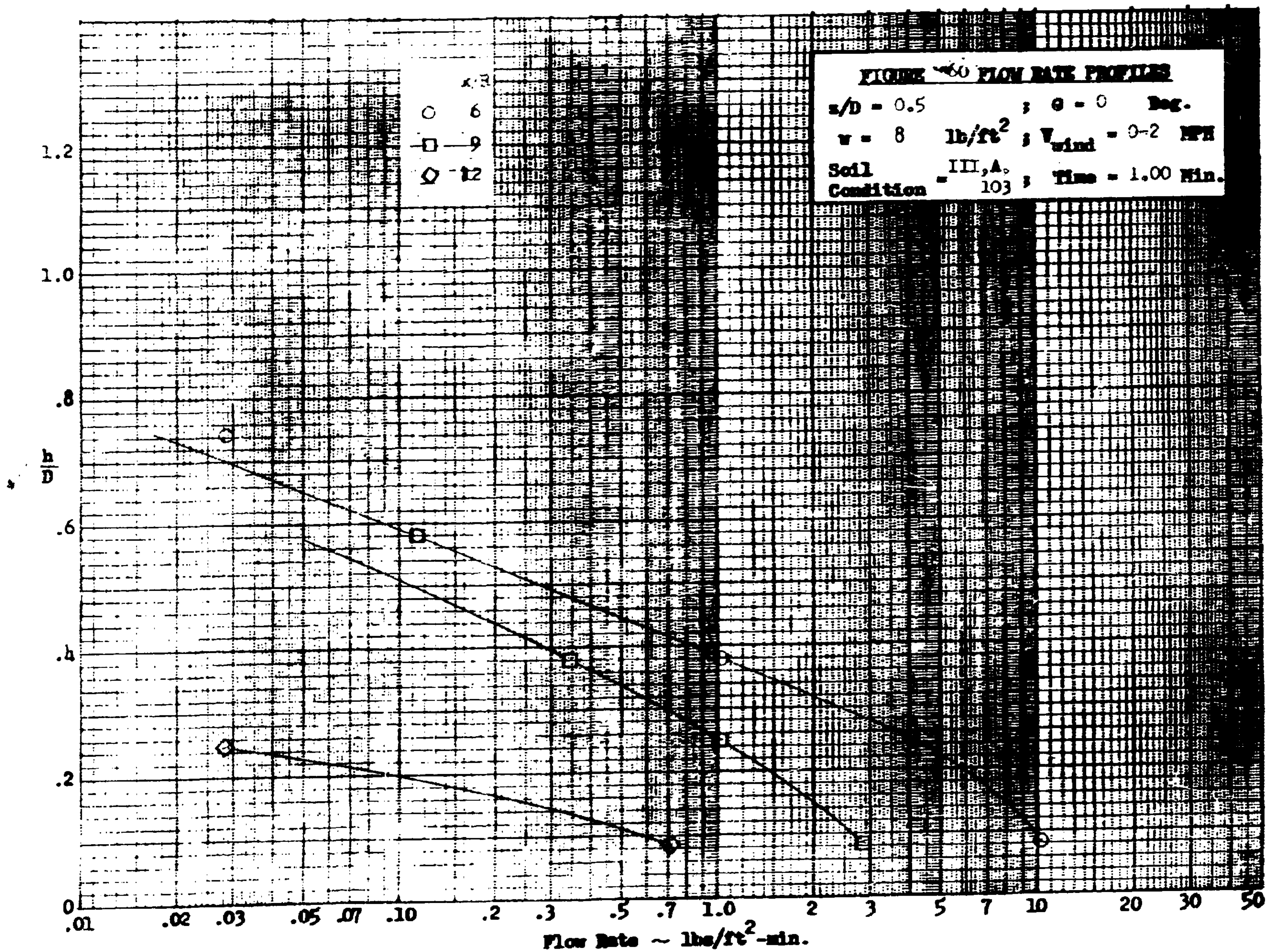


FIGURE 60 FLOW RATE PROFILES
s/D = 0.5 ; θ = 0 Deg.
w = 8 lb/ft² ; V wind = 0-2 MPH
Soil Condition = III, A, 103 ; Time = 1.00 Min.
x/B
6
9
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

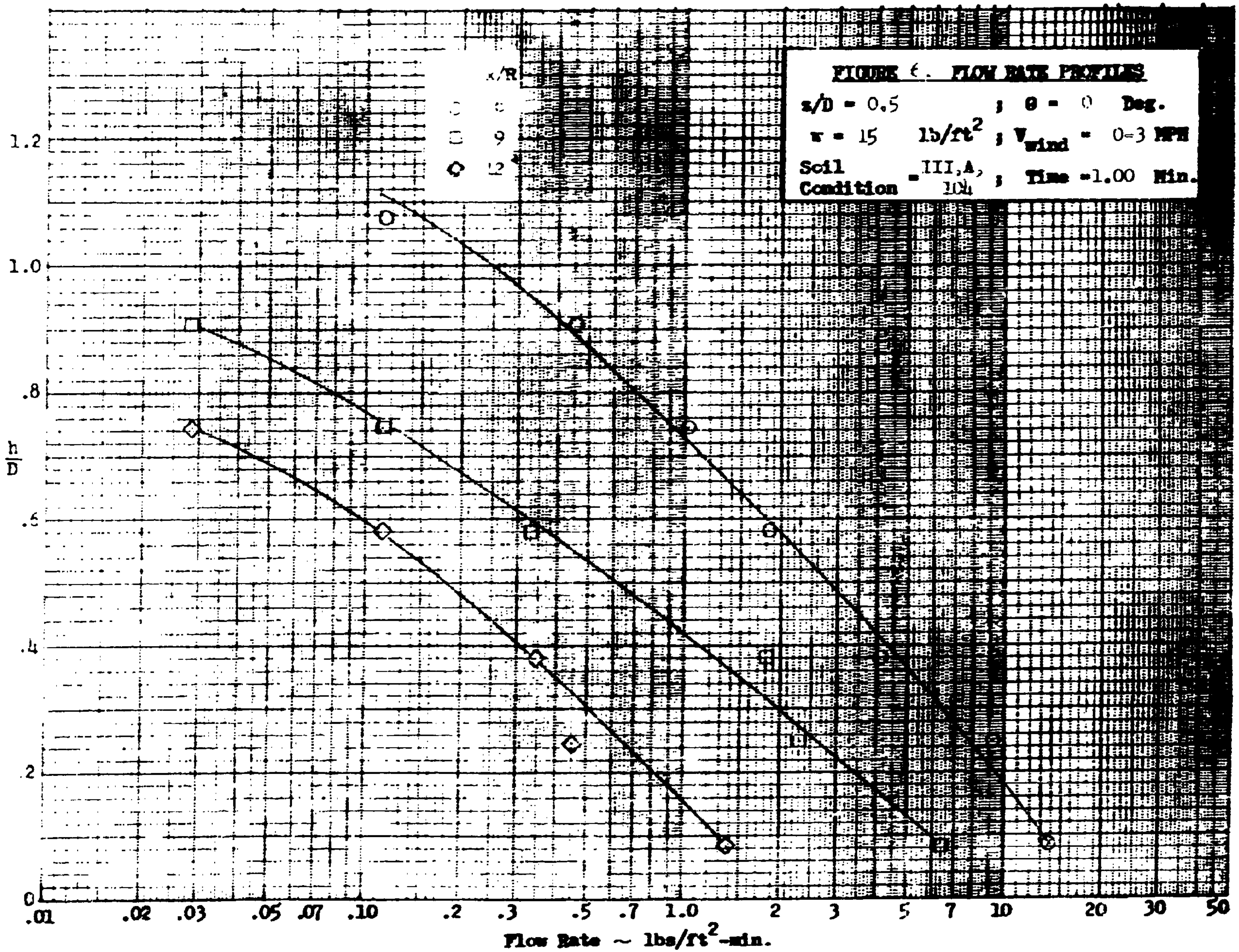


FIGURE 6. FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 15 lb/ft² ; V wind = 0-3 MPH
Soil Condition = III,A,104 ; Time = 1.00 Min.
x/R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

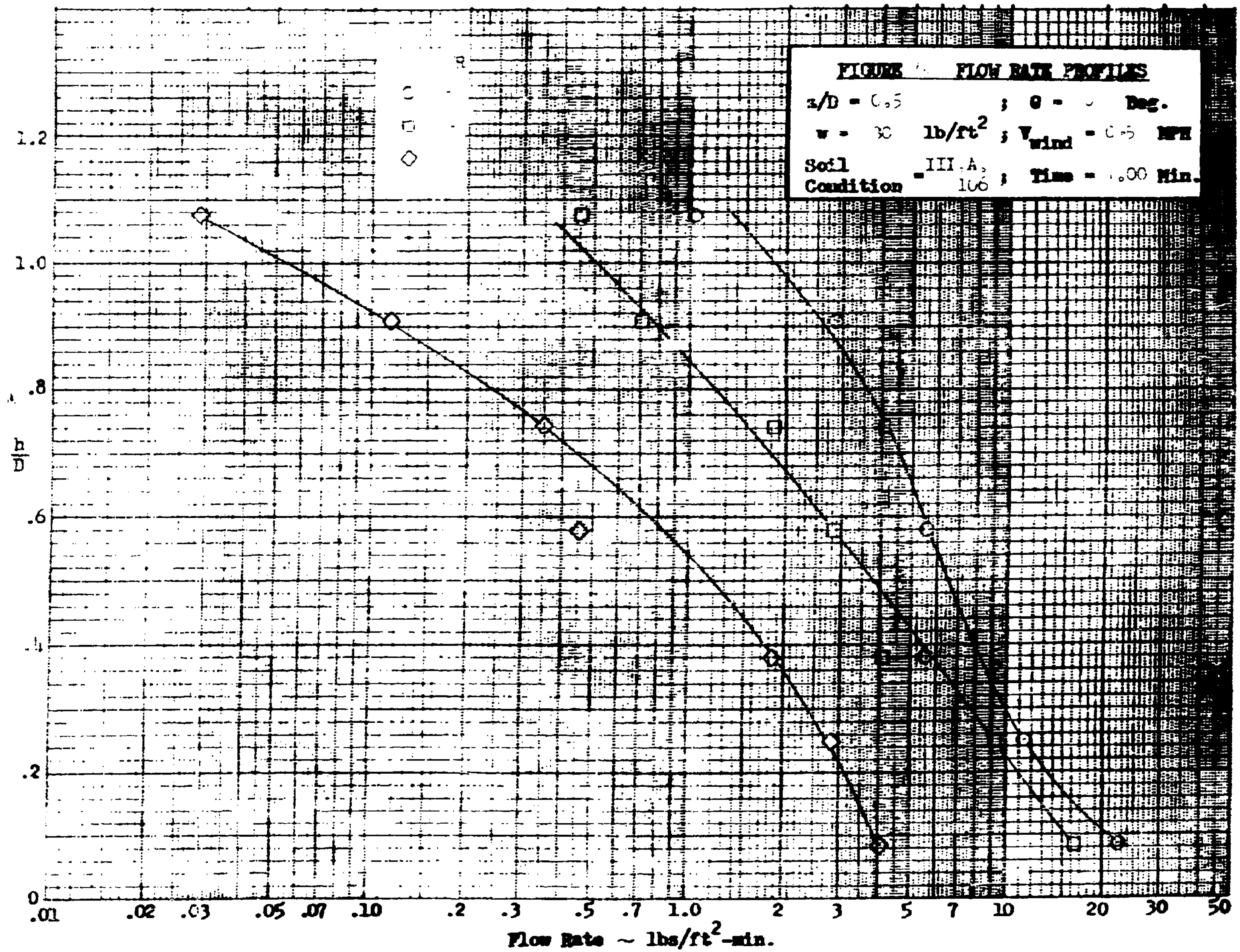


FIGURE FLOW RATE PROFILES
z/D = 0.5 ; θ = Deg.
w = 30 lb/ft^2 ; V_{wind} = MPH
Soil Condition = III.A, 106 ; Time = Min.
$\frac{h}{D}$
1.2
1.0
.8
.6
.2
0
.01 .02 .03 .05 .07 .10 .2 .3 .5 .7 1.0 2 3 5 7 10 20 30 50
Flow Rate ~ lbs/ft^2-min.

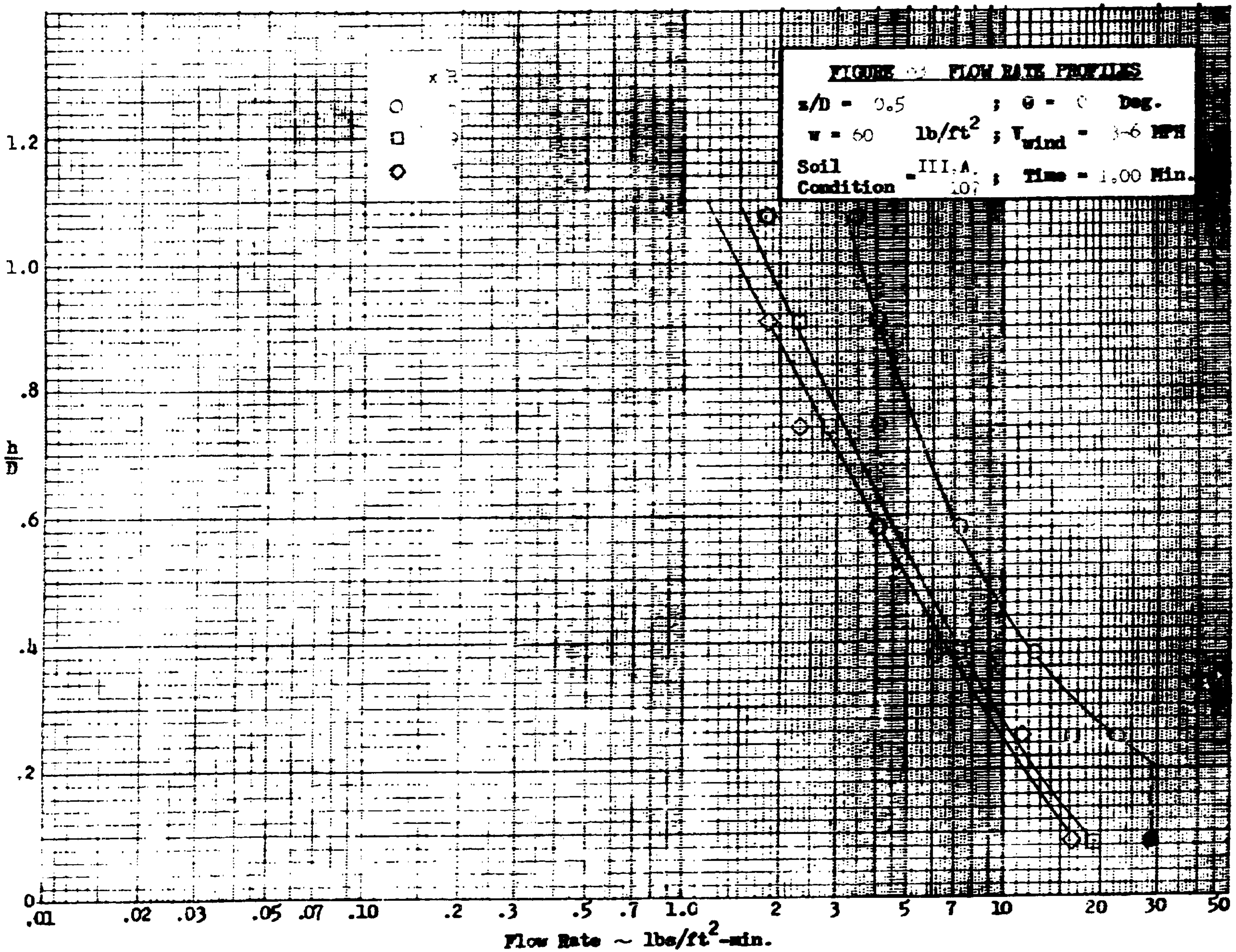


FIGURE FLOW RATE PROFILES
s/D = 0.5 ; θ = 0 Deg.
w = 60 lb/ft² ; V_wind = 3-6 MPH
Soil Condition = III.A. 107 ; Time = 1.00 Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

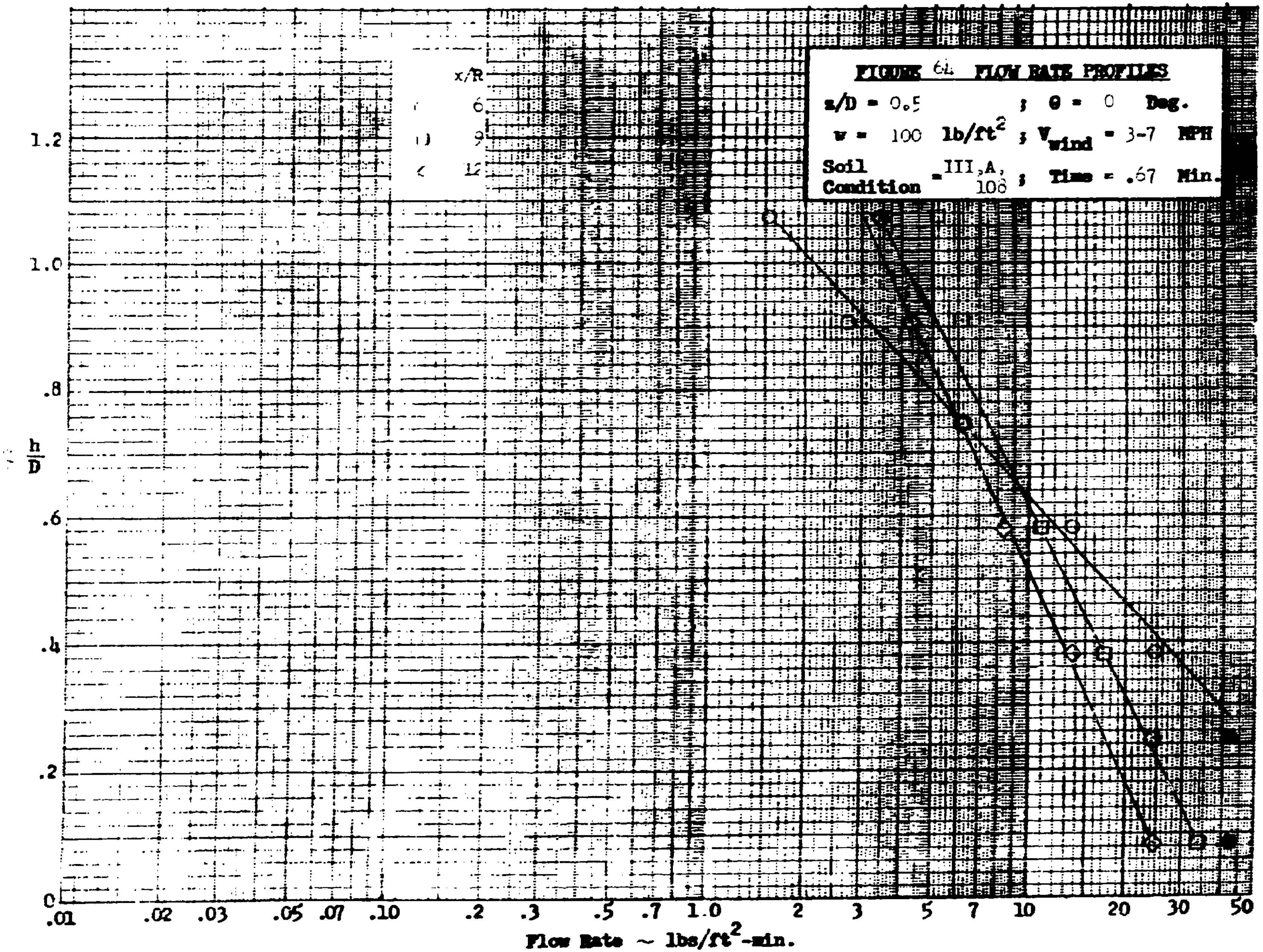


FIGURE 64 FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 100 lb/ft² ; V wind = 3-7 MPH
Soil Condition = III,A,108 ; Time = .67 Min.
x/R
6
9
12
1.2
1.0
.8
h/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

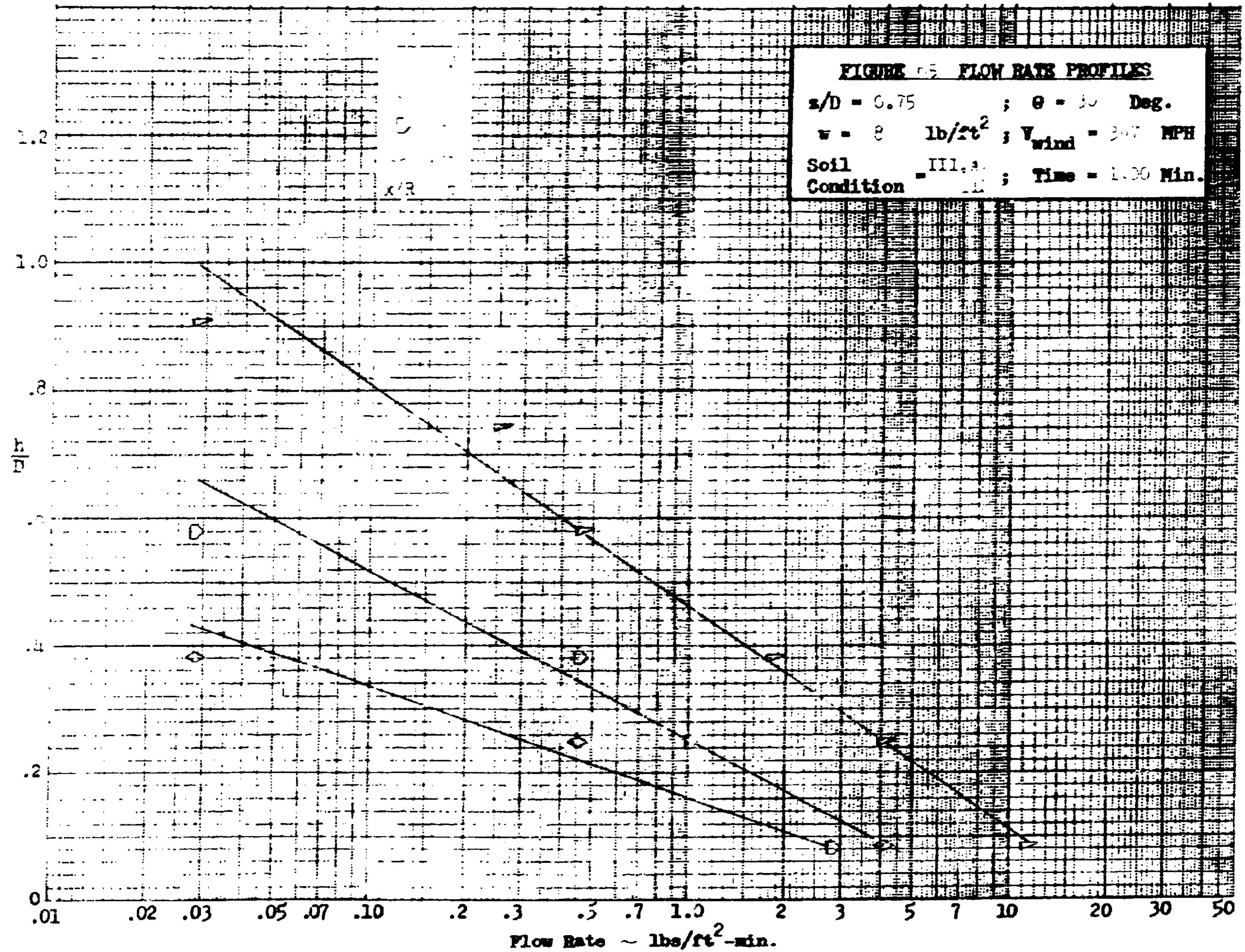


FIGURE FLOW RATE PROFILES
z/D = 0.75 ; θ = Deg.
w = 8 lb/ft^2 ; V_wind = MPH
Soil Condition = ; Time = Min.
h/D
1.2
1.0
.8
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

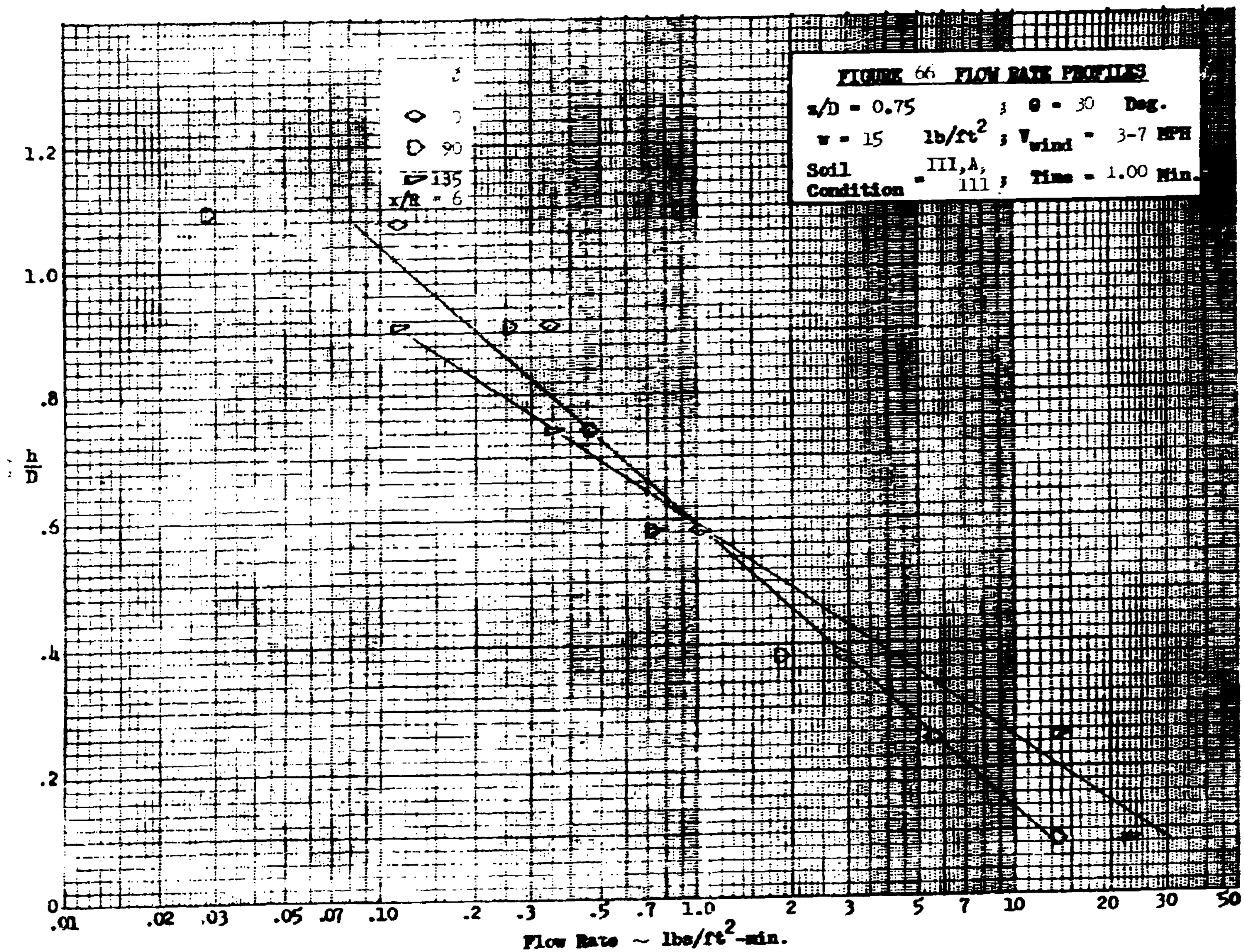


FIGURE 66 FLOW RATE PROFILES
x/D = 0.75 ; θ = 30 Deg.
w = 15 lb/ft² ; V_wind = 3-7 MPH
Soil Condition = III,A, 111 ; Time = 1.00 Min.
0
90
135
x/R = 6
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

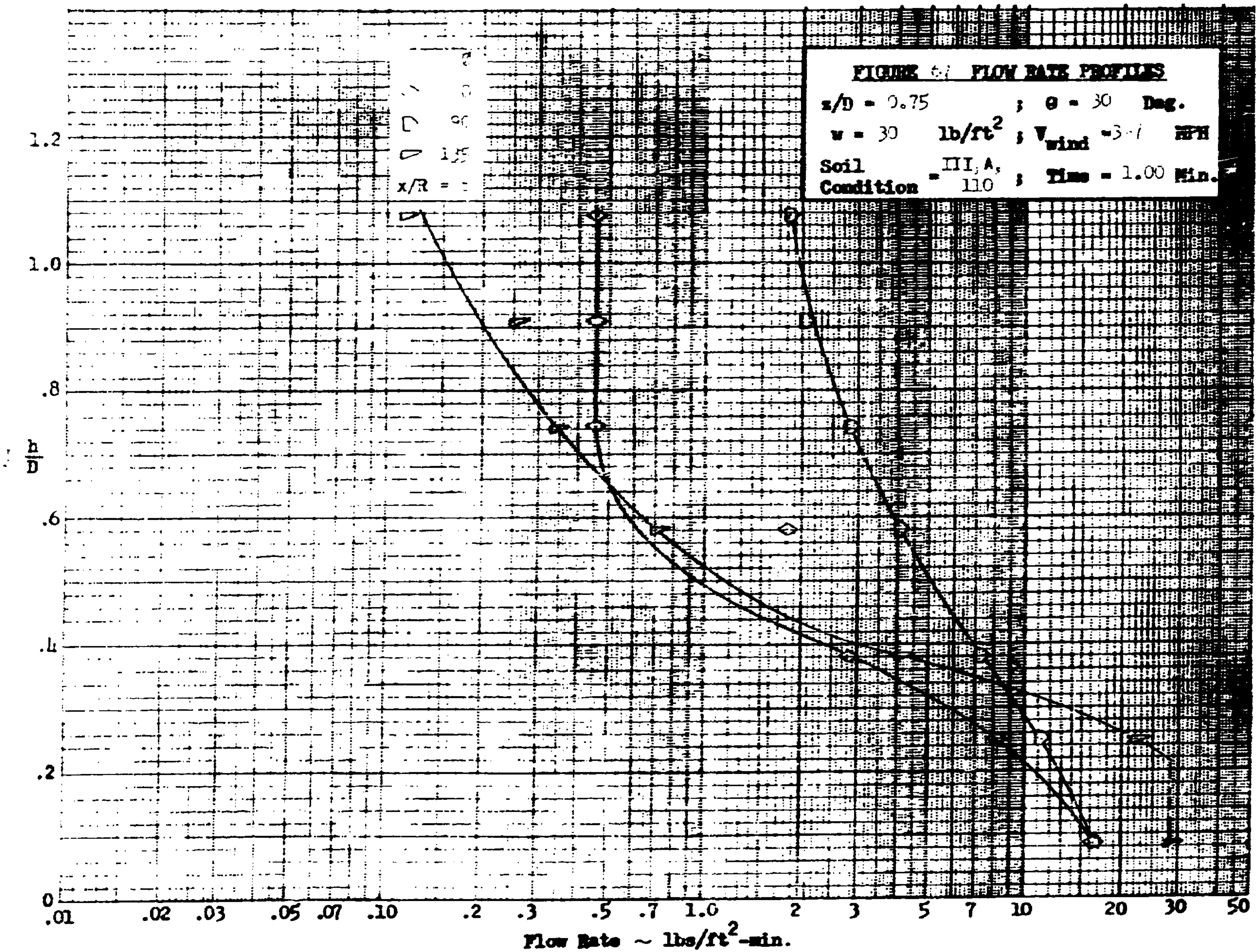


FIGURE 67 FLOW RATE PROFILES
x/D = 0.75 ; θ = 30 Deg.
w = 30 lb/ft² ; V_wind = 3.7 MPH
Soil Condition = III, A, 110 ; Time = 1.00 Min.
x/R =
0
90
135
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

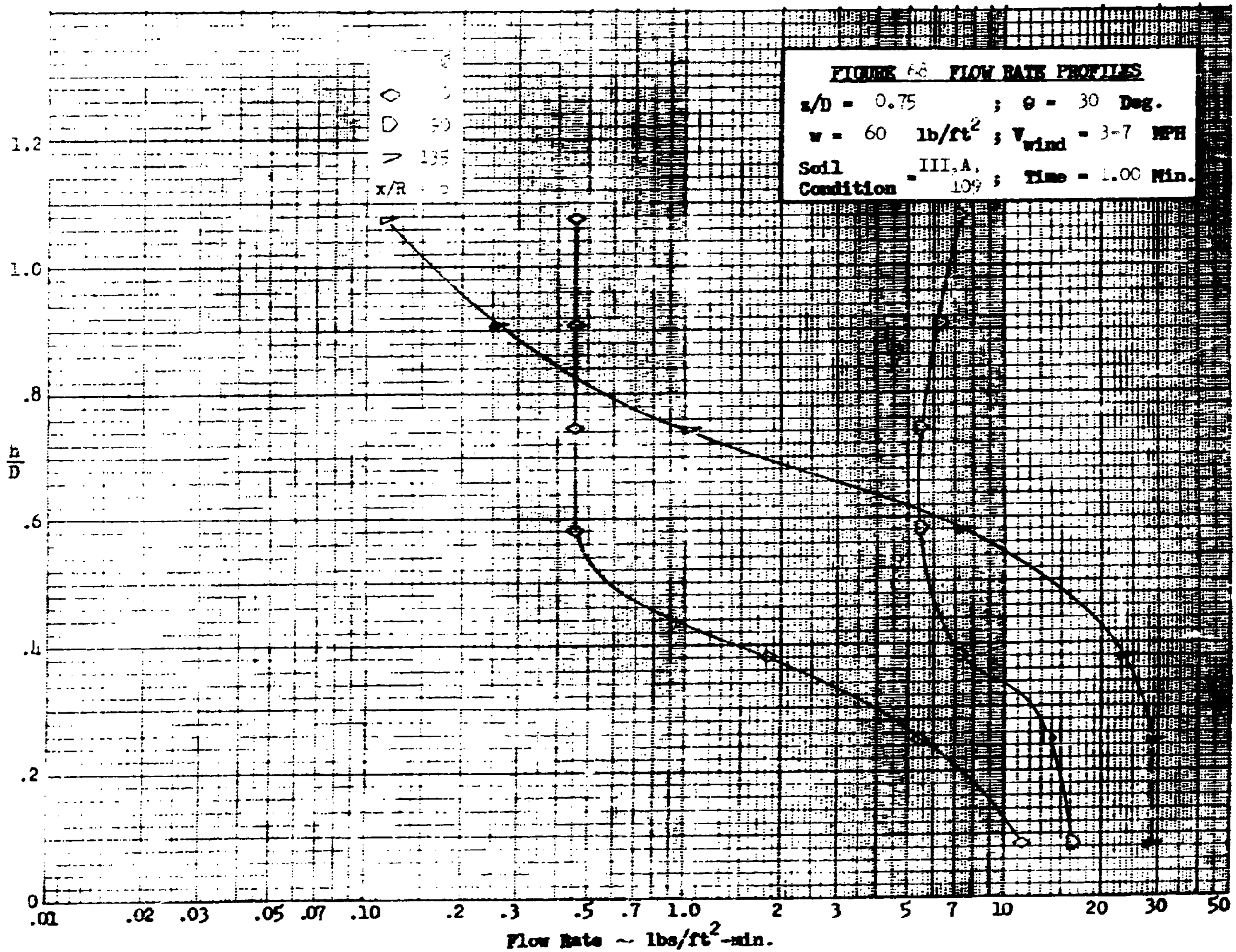


FIGURE 68 FLOW RATE PROFILES
z/D = 0.75 ; θ = 30 Deg.
w = 60 lb/ft² ; V wind = 3-7 MPH
Soil Condition = III, A, 109 ; Time = 1.00 Min.
x/R
90
135
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

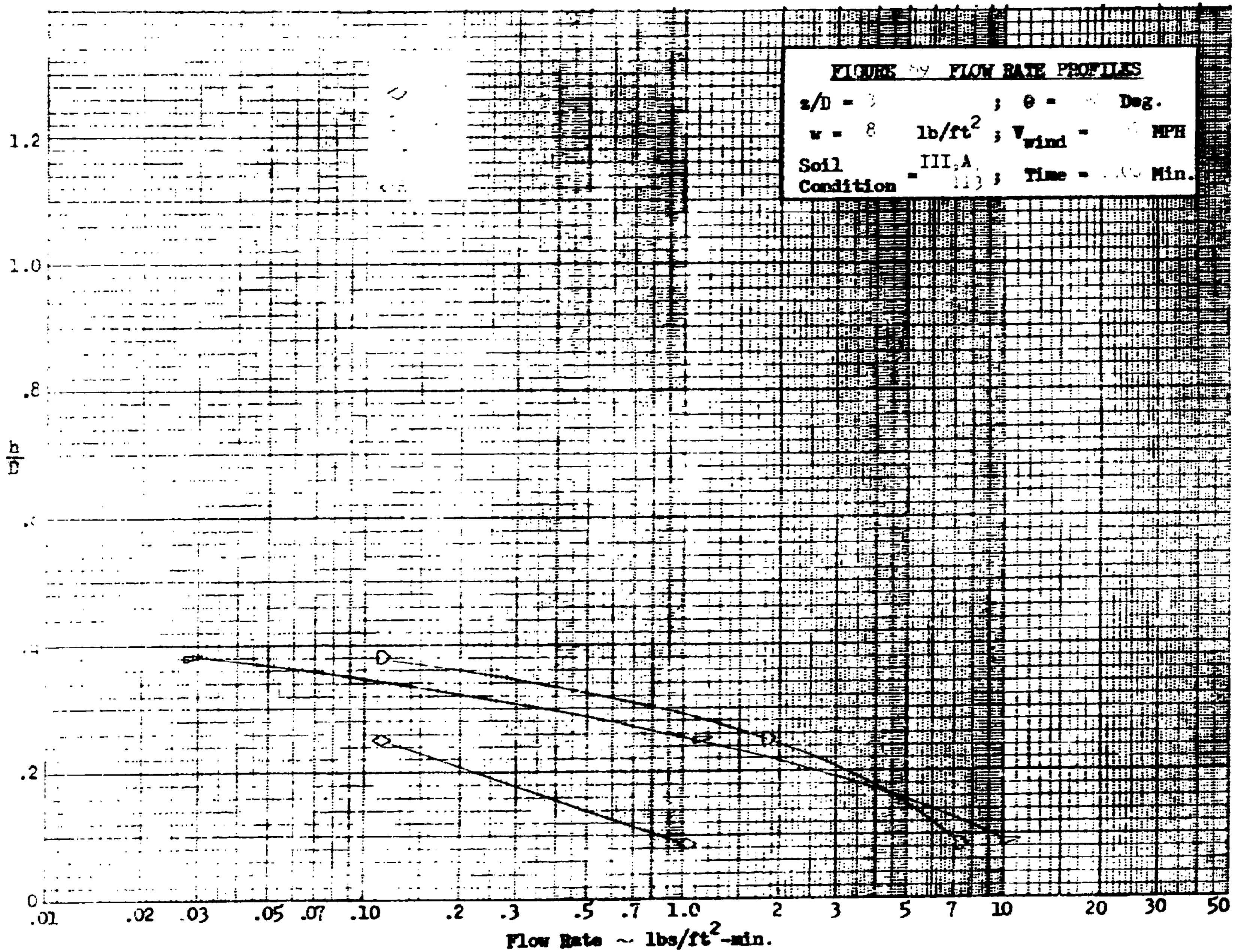


FIGURE 59 FLOW RATE PROFILES
z/D = ; θ = Deg.
w = 8 lb/ft² ; V_wind = MPH
Soil Condition = III,A ; Time = Min.
1.2
1.0
.8
h/D
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

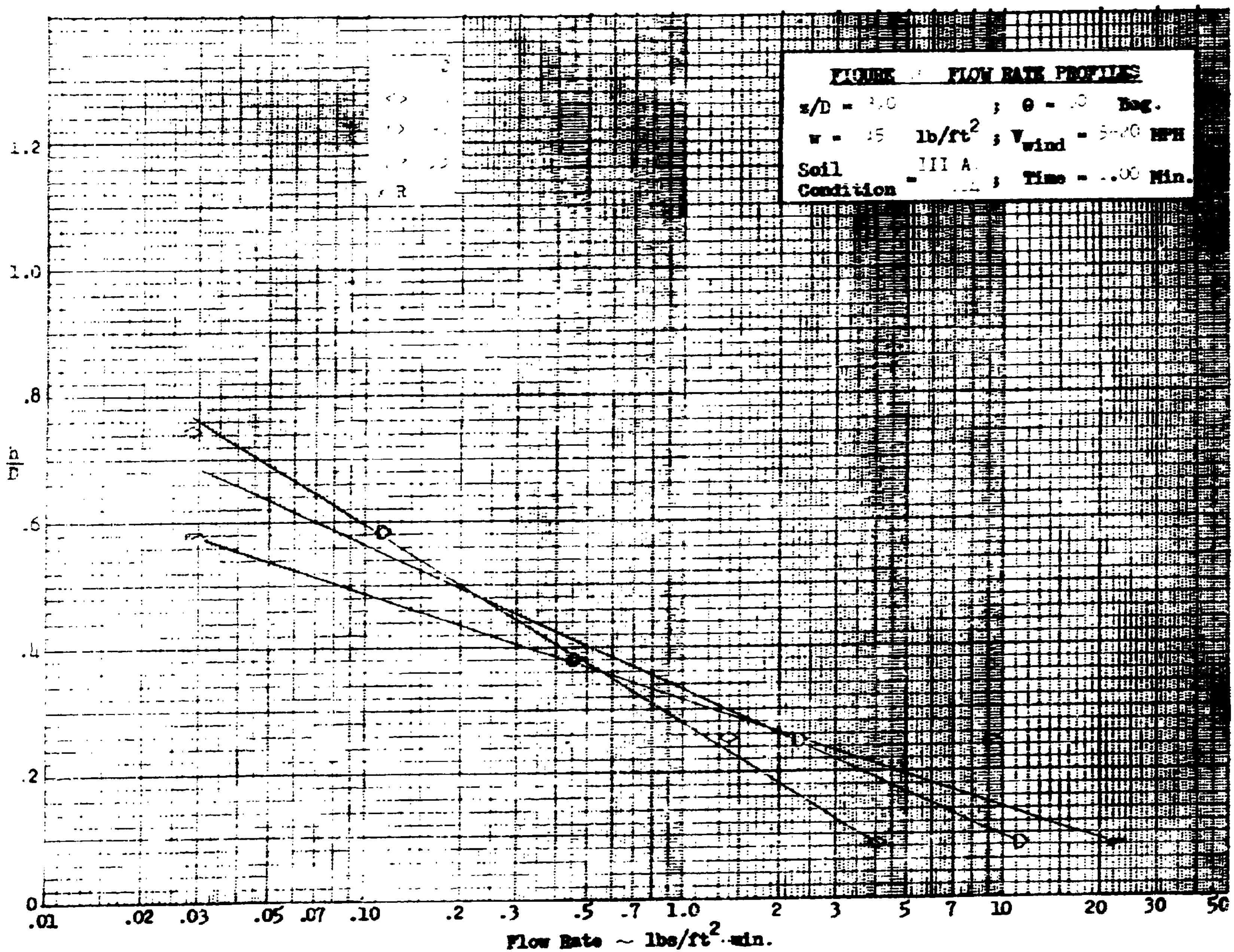


FIGURE FLOW RATE PROFILES
x/D = 3.0 ; θ = 0 Deg.
w = 15 lb/ft^2 ; V_{wind} = 5-20 MPH
Soil Condition = III A ; Time = .00 Min.
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2·min.

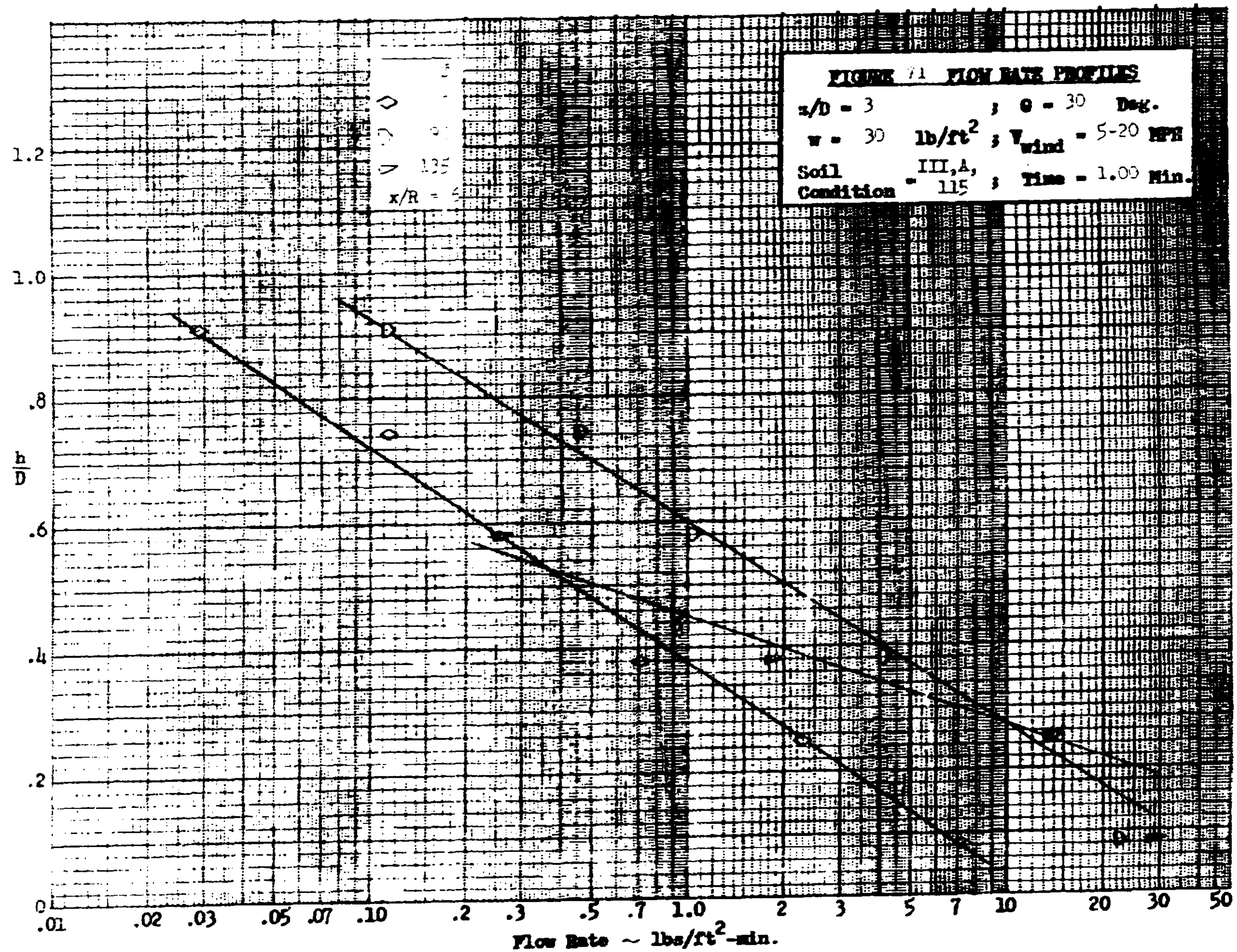


FIGURE 71 FLOW RATE PROFILES
x/D = 3 ; Θ = 30 Deg.
w = 30 lb/ft² ; V_wind = 5-20 MPH
Soil Condition = III,A, 115 ; Time = 1.00 Min.
135
x/R =
1.2
1.0
.8
h/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

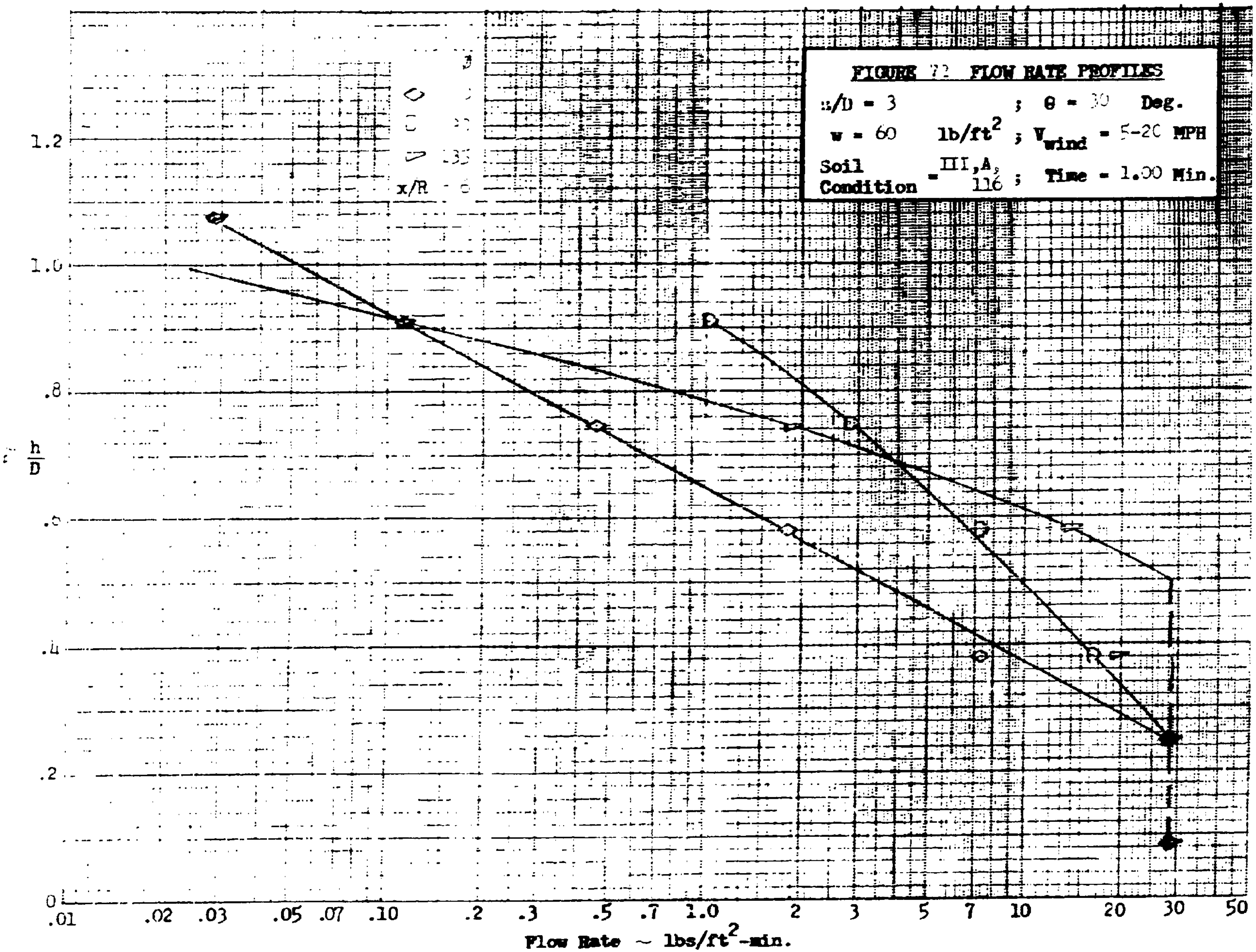


FIGURE 72 FLOW RATE PROFILES
x/D = 3 ; θ = 30 Deg.
w = 60 lb/ft² ; V_wind = 5-20 MPH
Soil Condition = III,A, 116 ; Time = 1.00 Min.
x/R
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

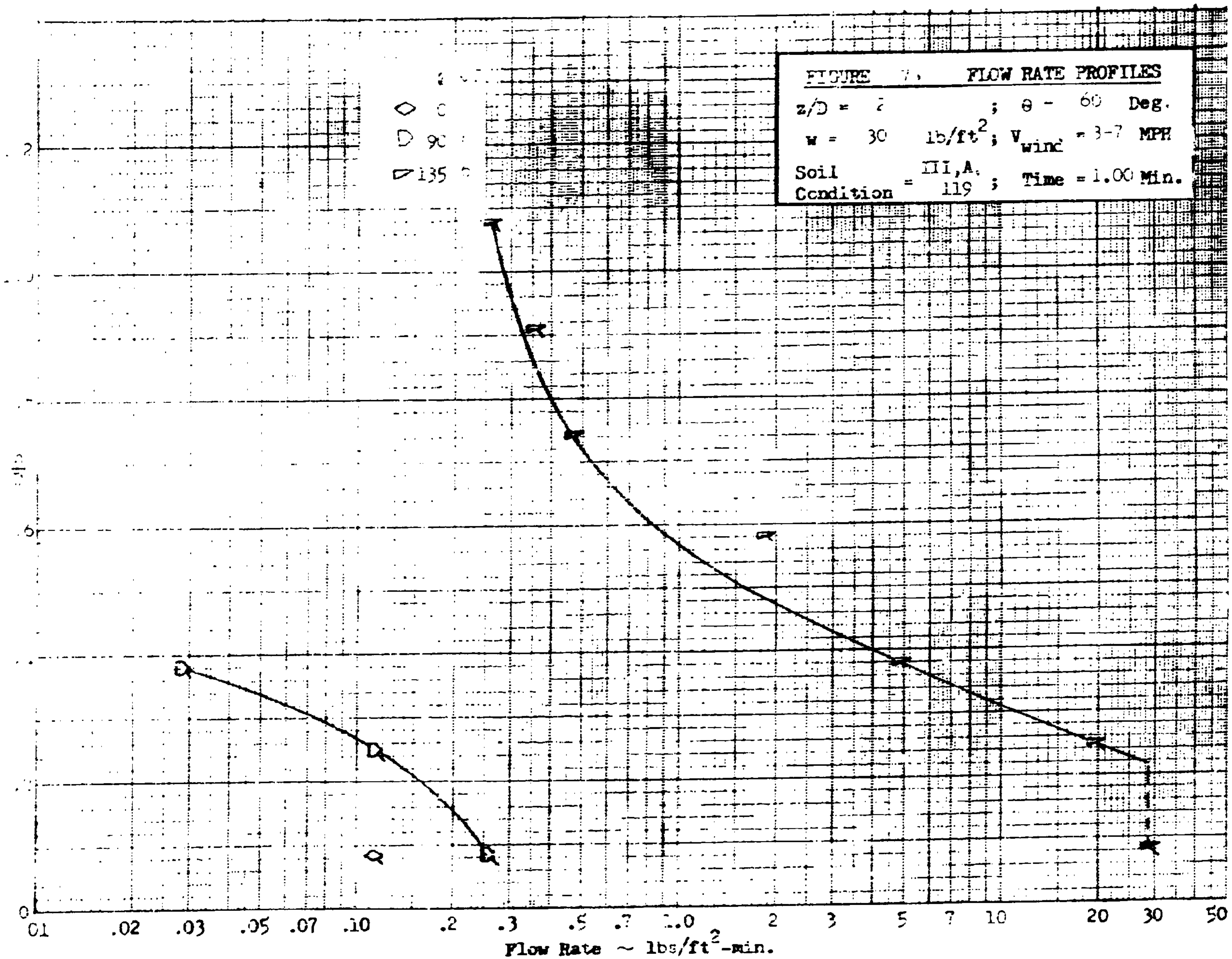


FIGURE 7, FLOW RATE PROFILES
z/D = 2 ; θ = 60 Deg.
w = 30 lb/ft²; V wind = 3-7 MPH
Soil Condition = III, A, 119 ; Time = 1.00 Min.
◇ 0
D 90
▱ 135
.2
.6
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

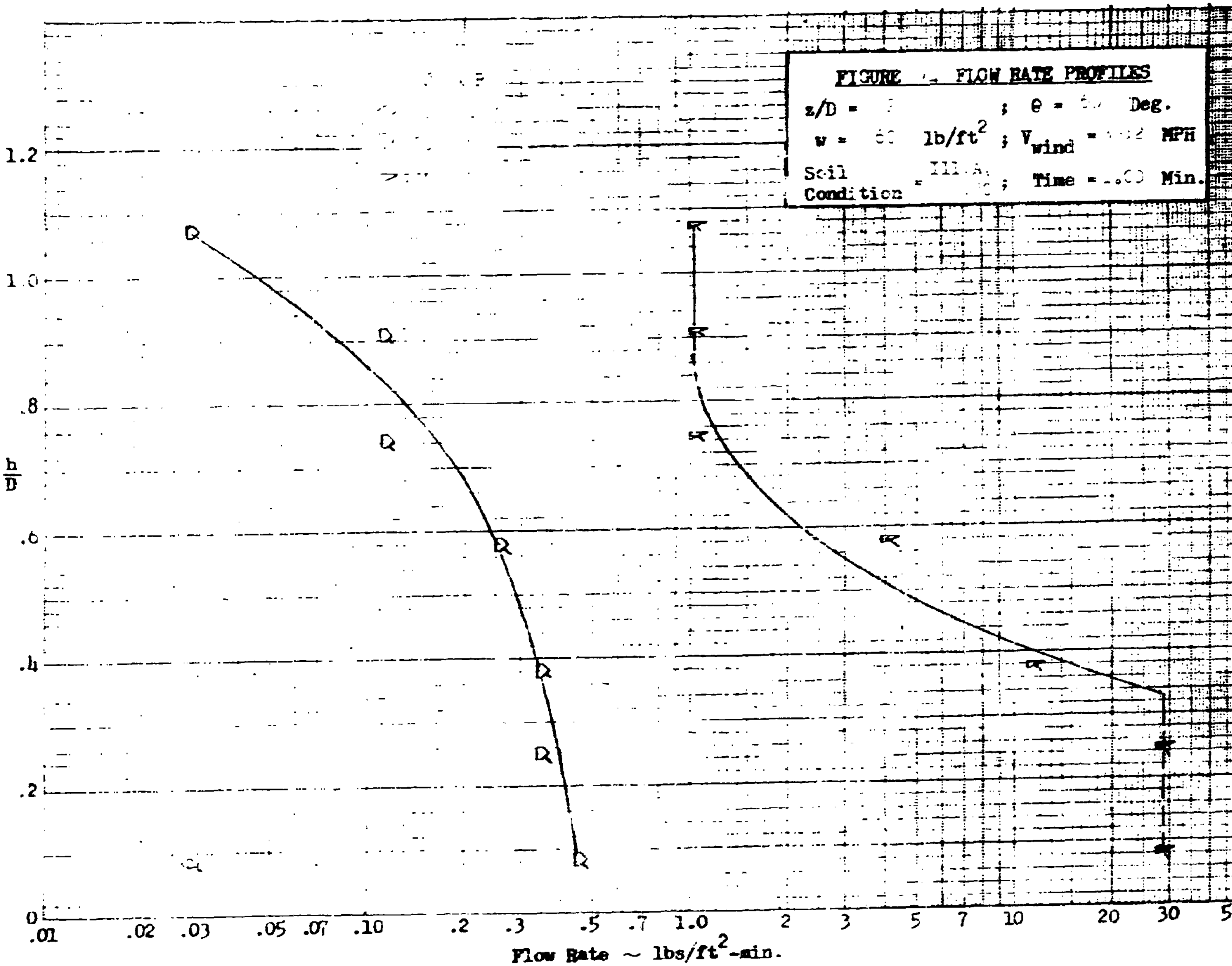
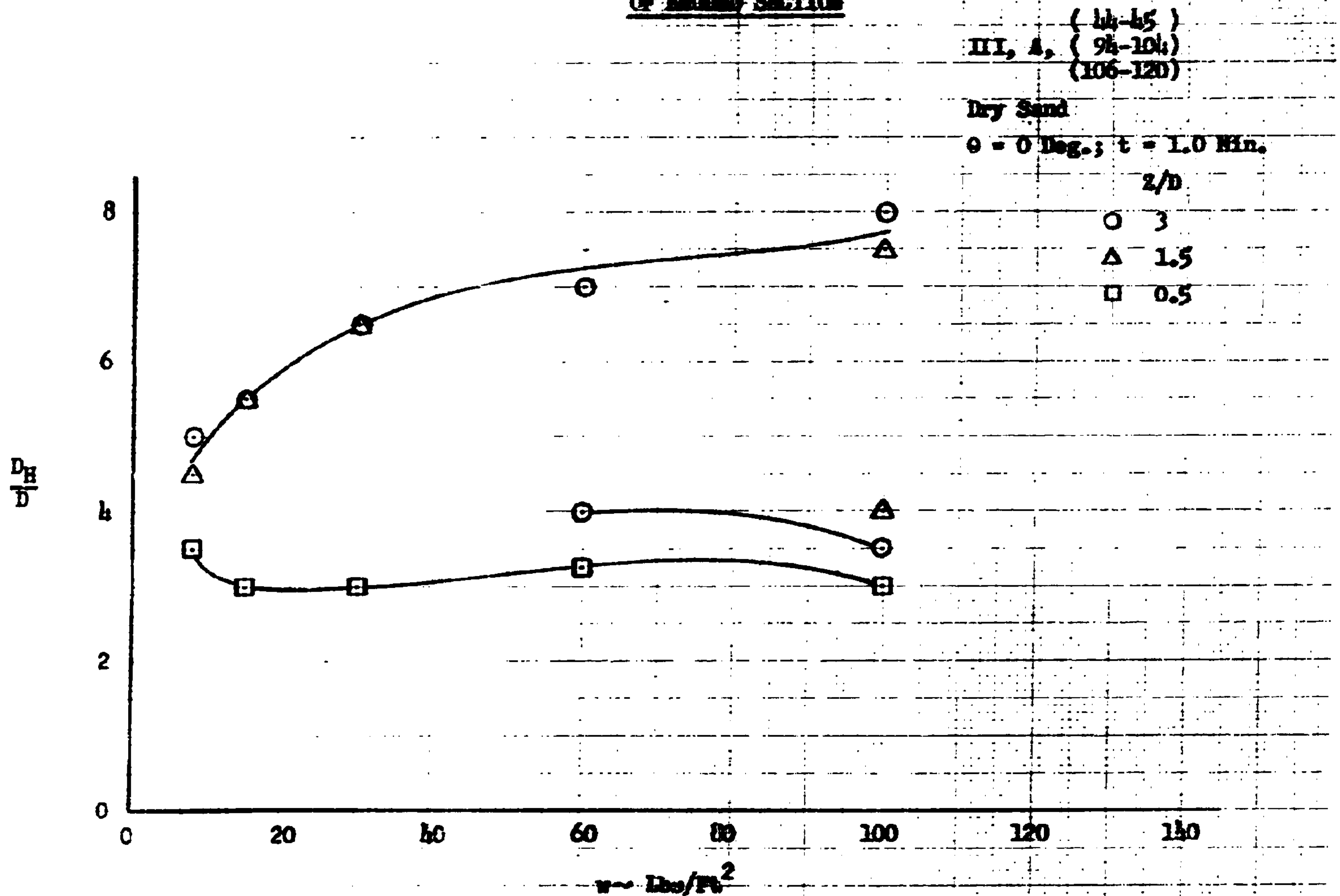


FIGURE FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft^2 ; V_{wind} = MPH
Soil Condition = ; Time = Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

FIGURE 75 RELATIVE DIAMETER OF [illegible] SECTION



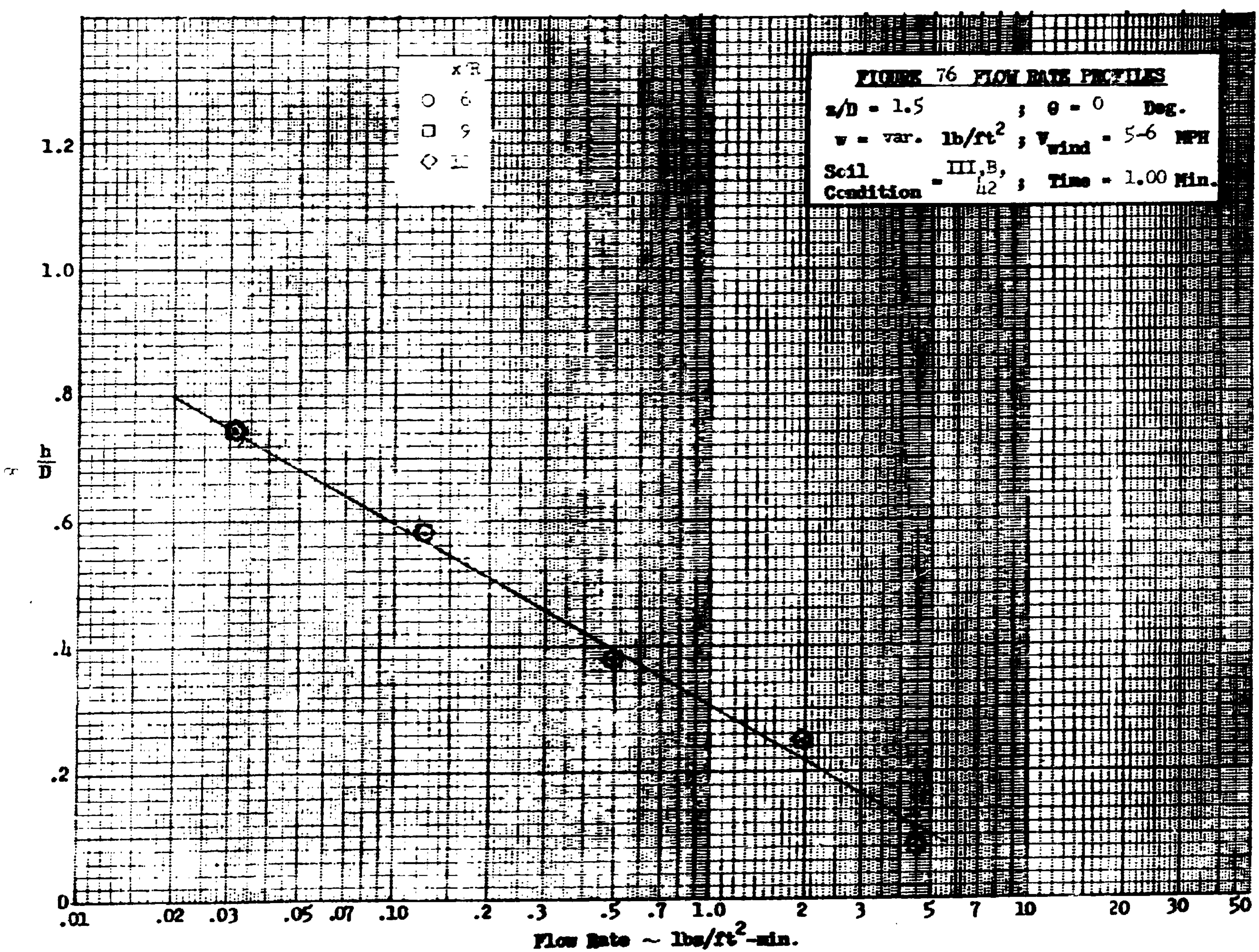


FIGURE 76 FLOW RATE PROFILES
z/D = 1.5 ; θ = 0 Deg.
w = var. lb/ft² ; V_wind = 5-6 MPH
Soil Condition = III, B, 42 ; Time = 1.00 Min.
x R
○ 6
□ 9
◇ 11
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

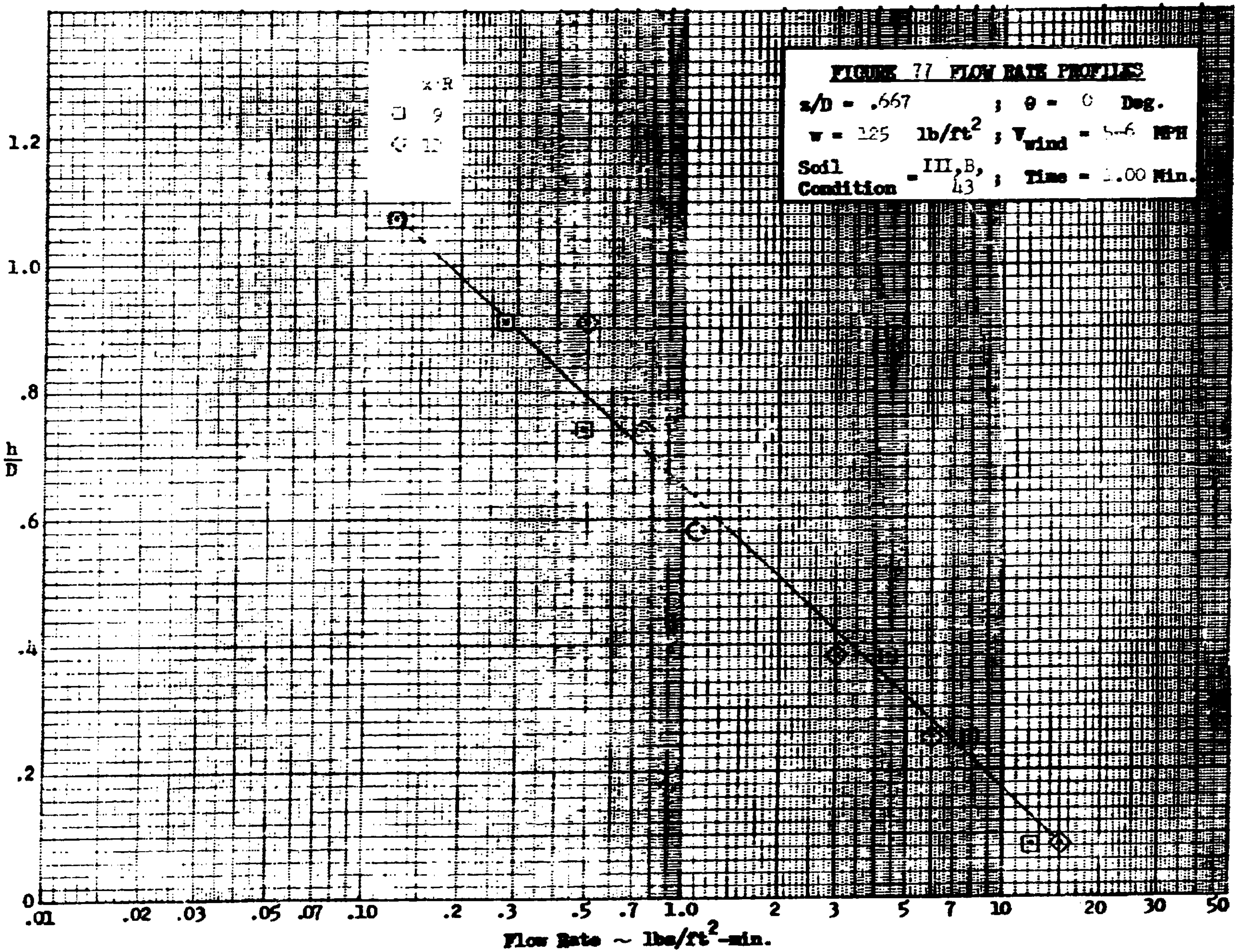


FIGURE 77 FLOW RATE PROFILES
x/D = .667 ; θ = 0 Deg.
w = 125 lb/ft^2 ; V_{wind} = 5-6 MPH
Soil Condition = III, B, 43 ; Time = 1.00 Min.
x·R
9
10
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

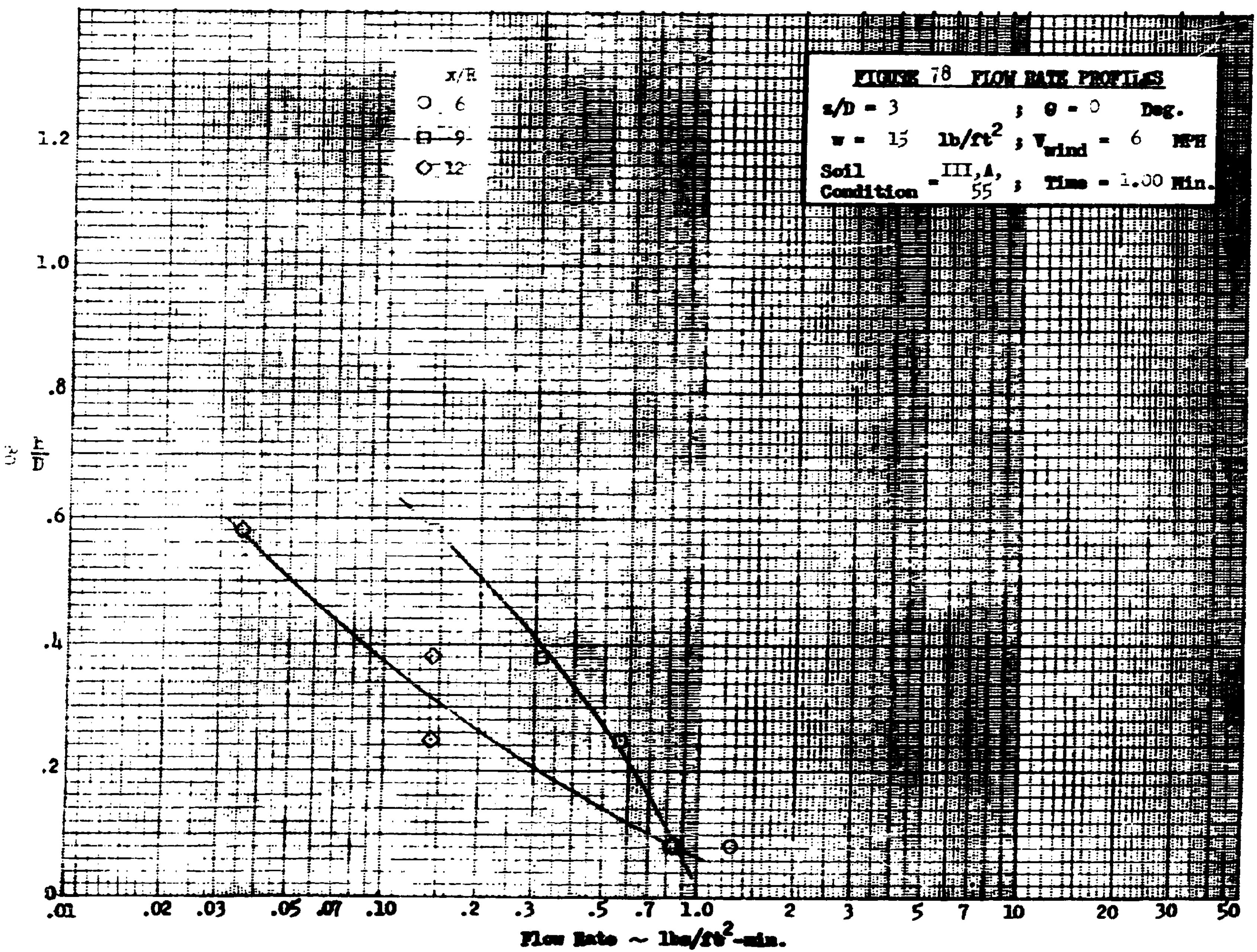


FIGURE 78 FLOW RATE PROFILES
s/D = 3 ; θ = 0 Deg.
w = 15 lb/ft² ; V_wind = 6 MPH
Soil Condition = III, A, 55 ; Time = 1.00 Min.
x/R
6
9
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbm/ft²-min.

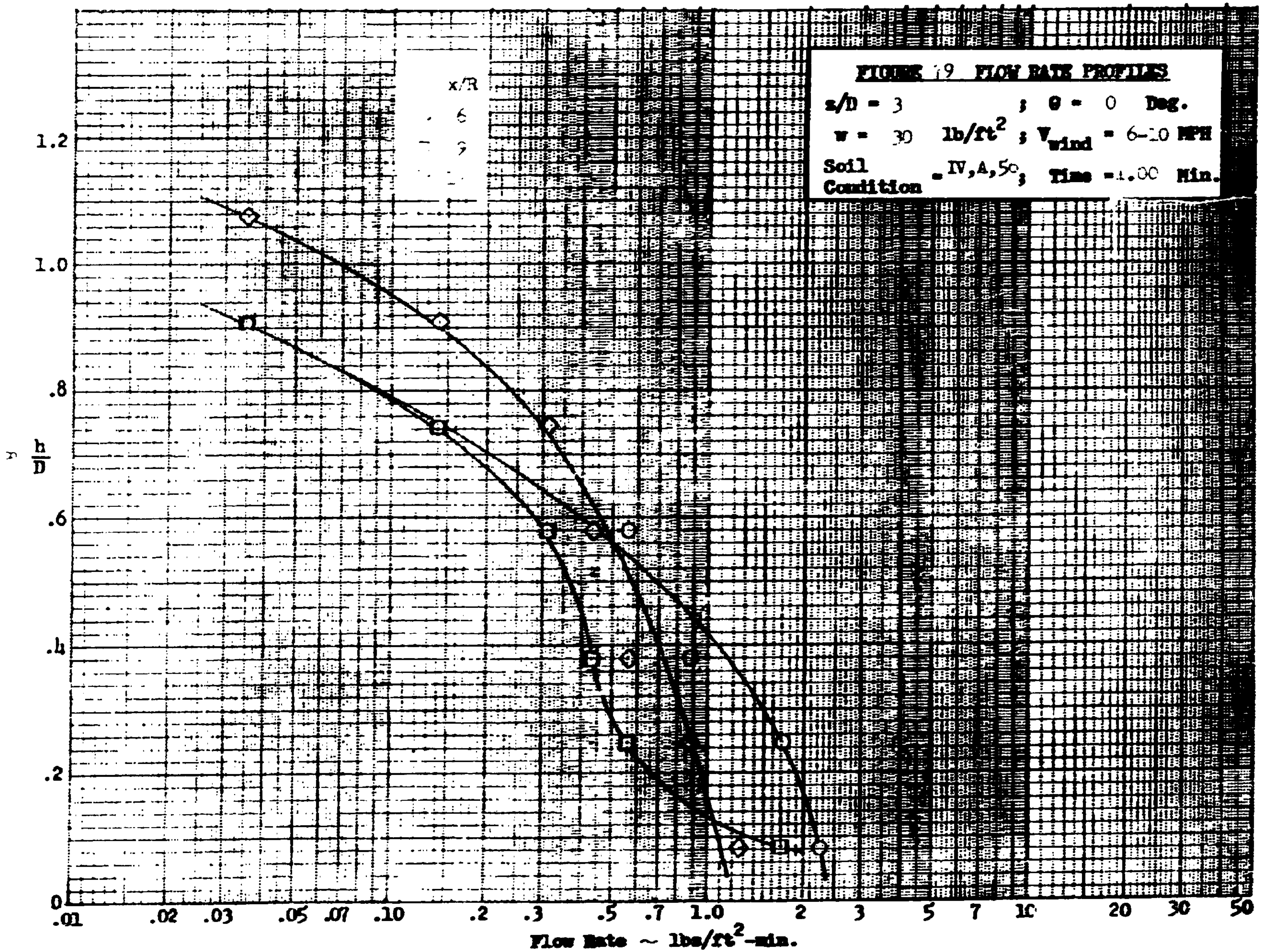


FIGURE 19 FLOW RATE PROFILES
s/D = 3 ; θ = 0 Deg.
w = 30 lb/ft² ; V_wind = 6-10 MPH
Soil Condition = IV,A,50 ; Time = 1.00 Min.
x/R
6
9
1.2
1.0
.8
h/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

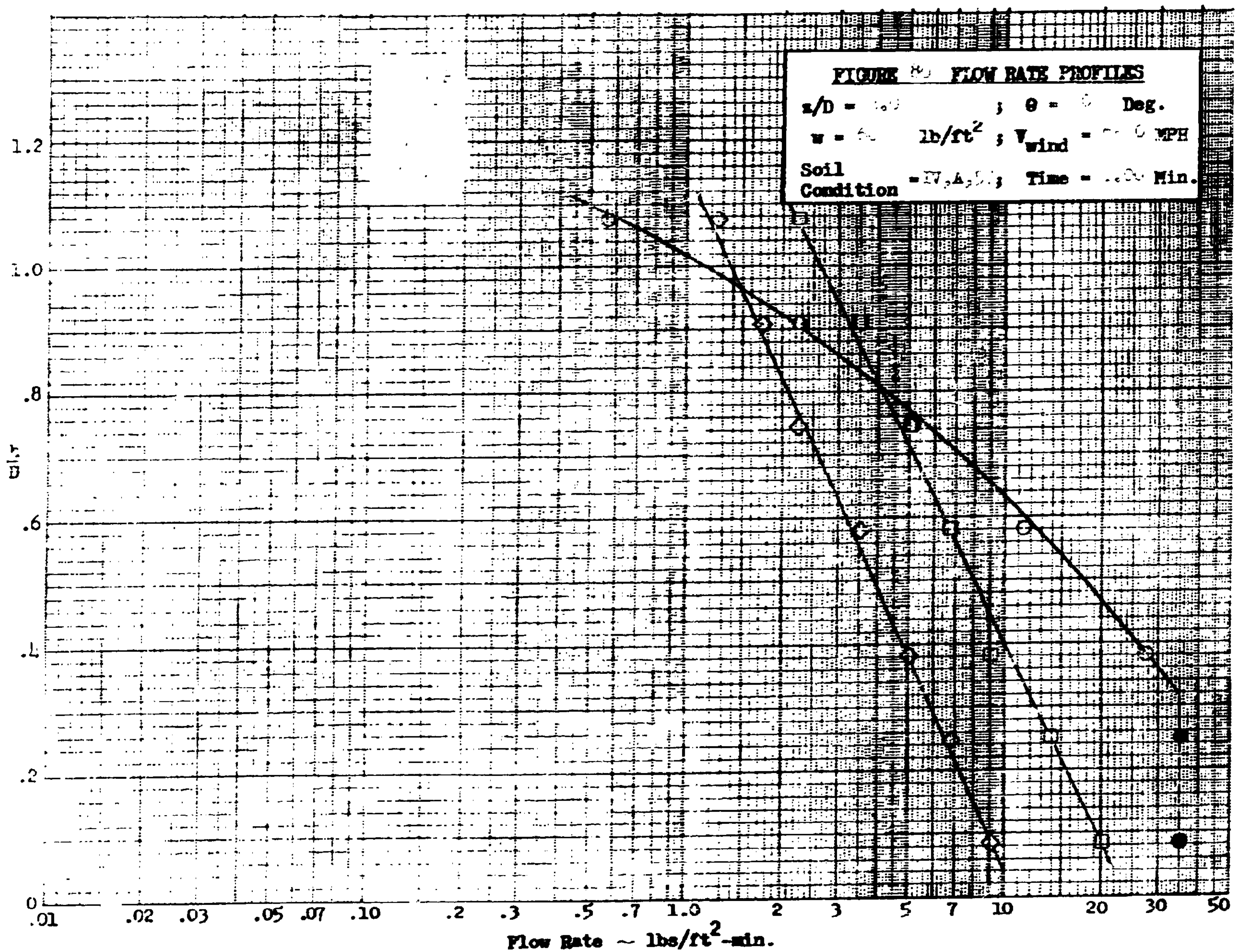


FIGURE FLOW RATE PROFILES
x/D = ; θ = Deg.
w = lb/ft^2 ; V_wind = MPH
Soil Condition = ; Time = Min.
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

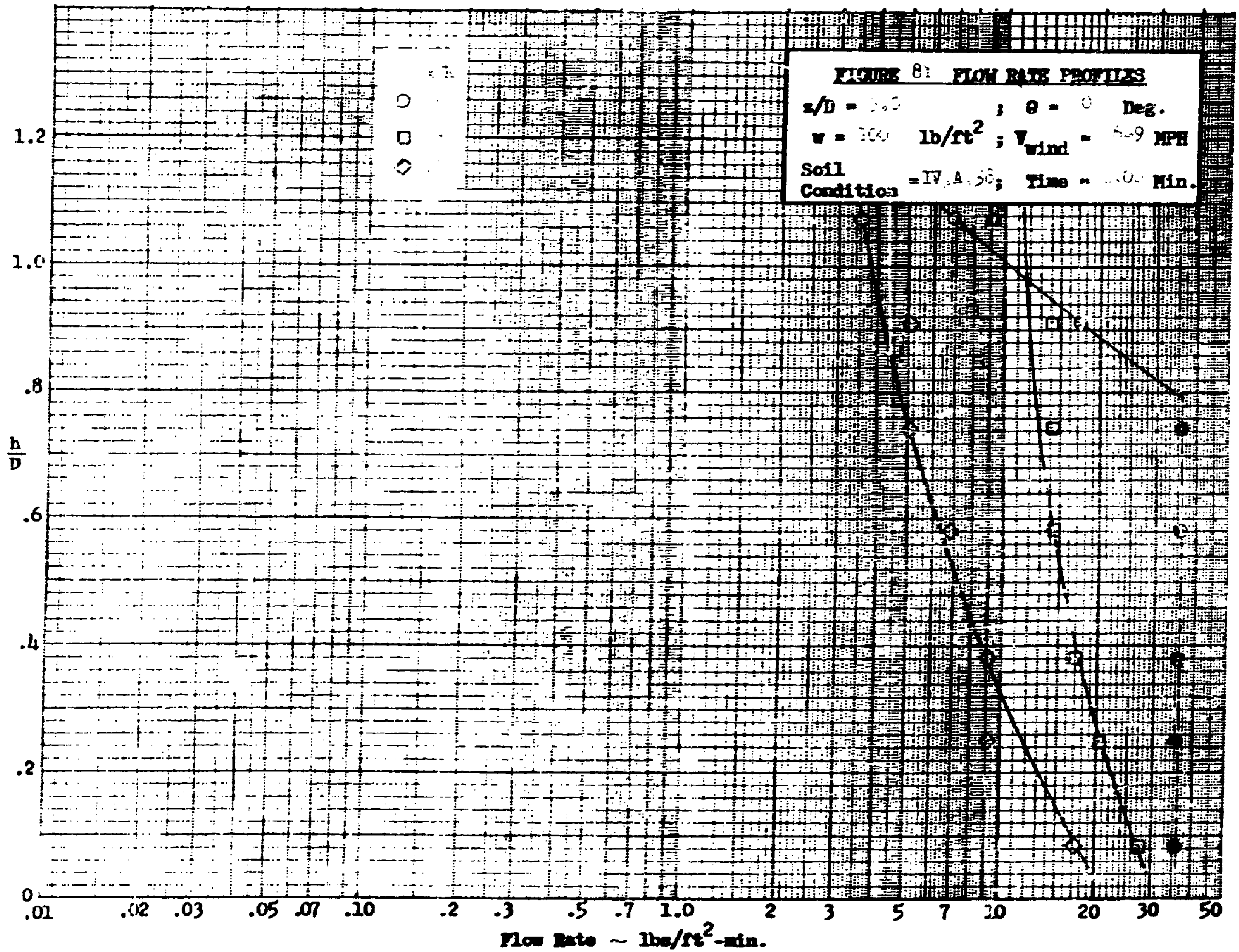


FIGURE 81 FLOW RATE PROFILES
Deg.
lb/ft²
MPH
Soil Condition
Time =
Min.
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

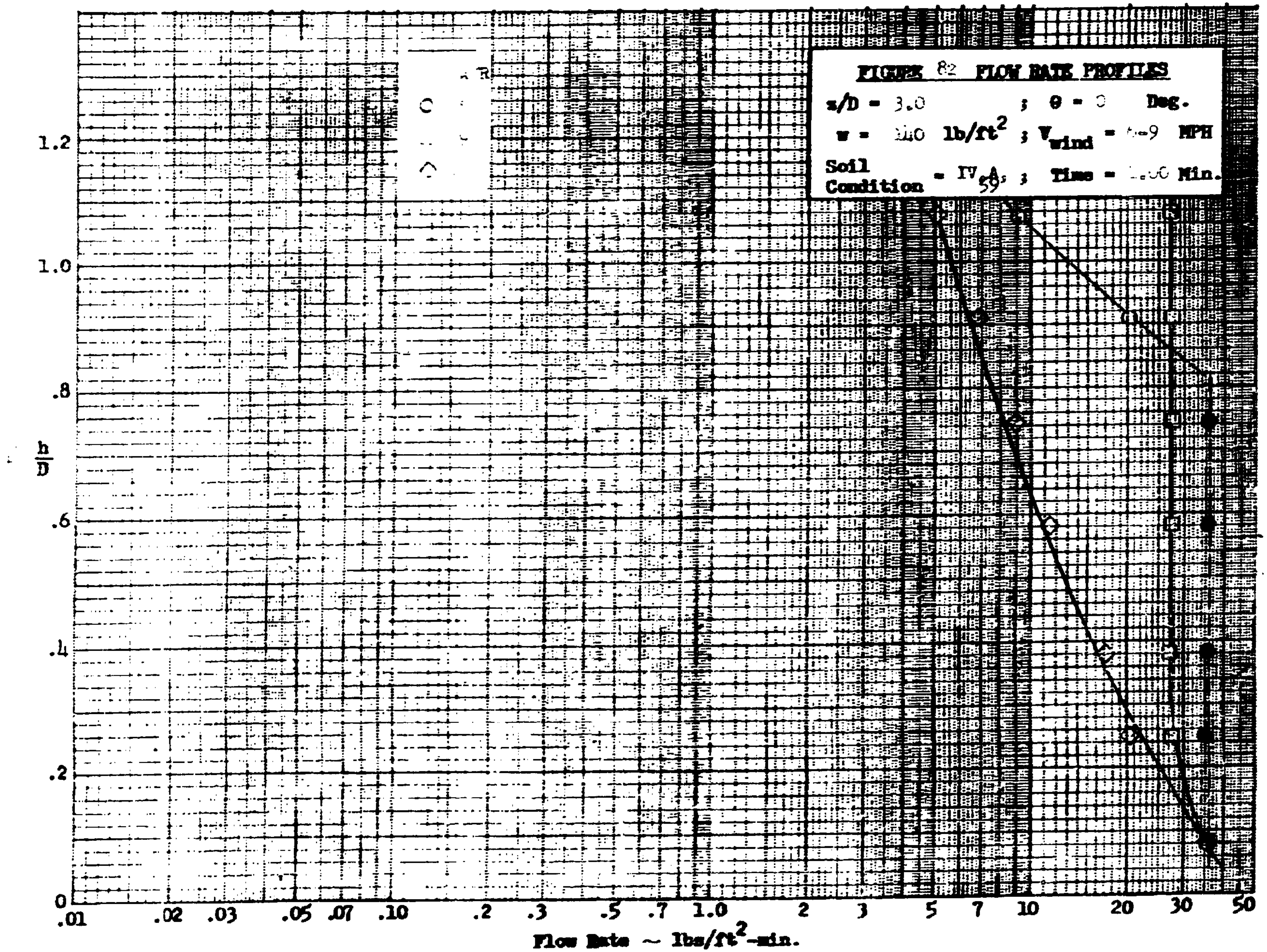


FIGURE 82 FLOW RATE PROFILES

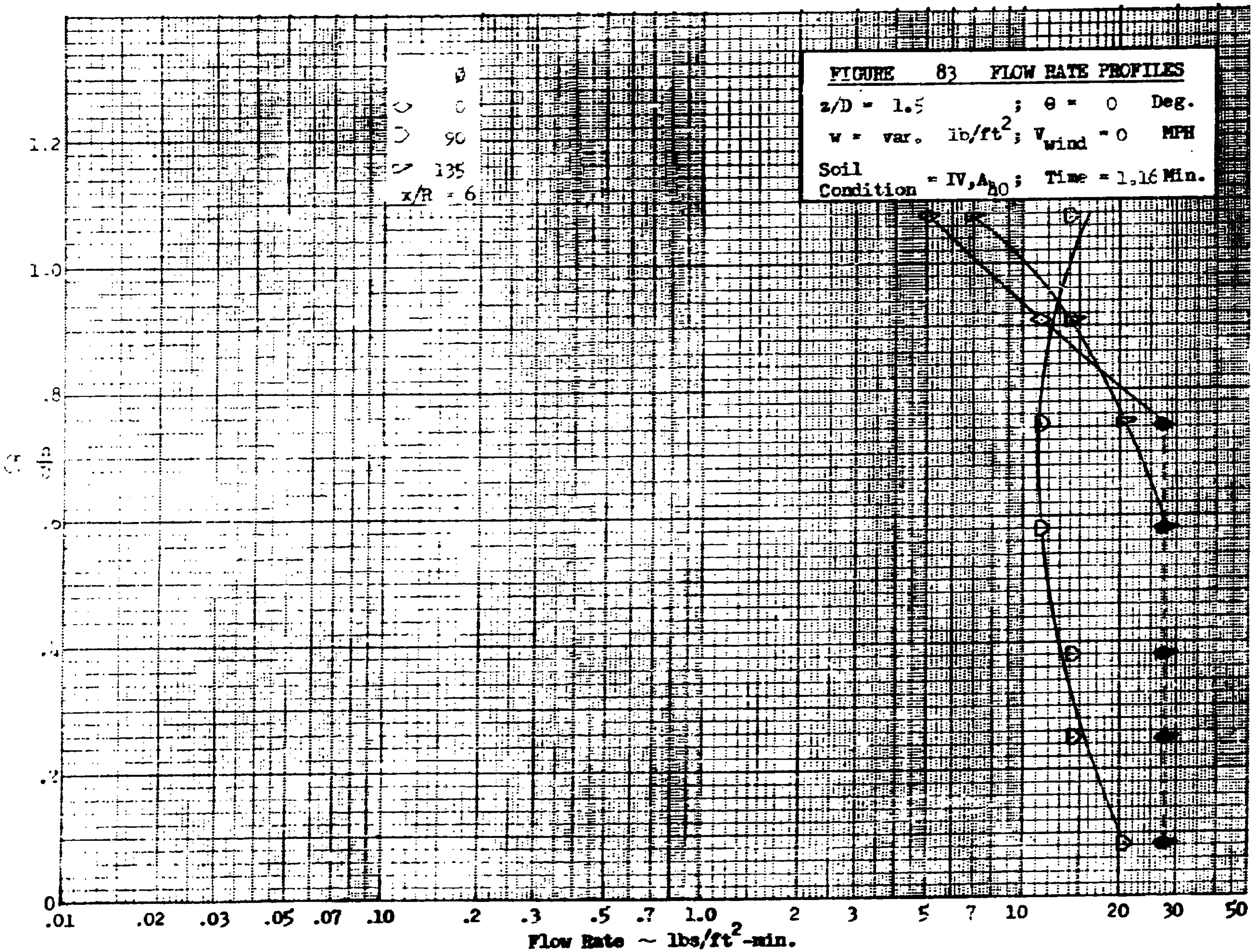


FIGURE 83 FLOW RATE PROFILES
z/D = 1.5 ; θ = 0 Deg.
w = var. lb/ft²; V wind = 0 MPH
Soil Condition = IV, A80 ; Time = 1.16 Min.
φ
0
90
135
x/R = 6
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

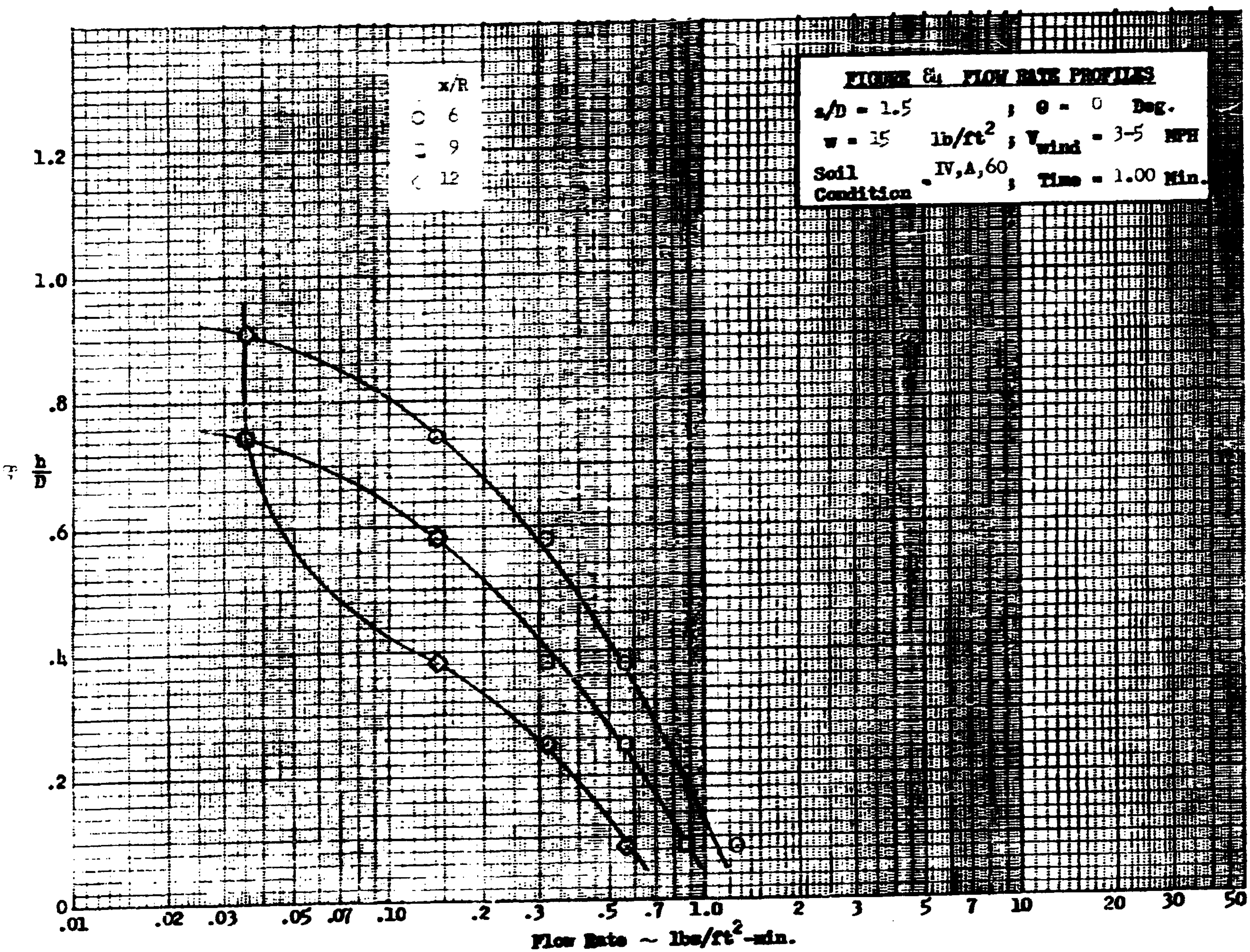


FIGURE 84 FLOW RATE PROFILES
a/D = 1.5 ; θ = 0 Deg.
w = 15 lb/ft² ; V_wind = 3-5 MPH
Soil Condition = IV,A,60 ; Time = 1.00 Min.
x/R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

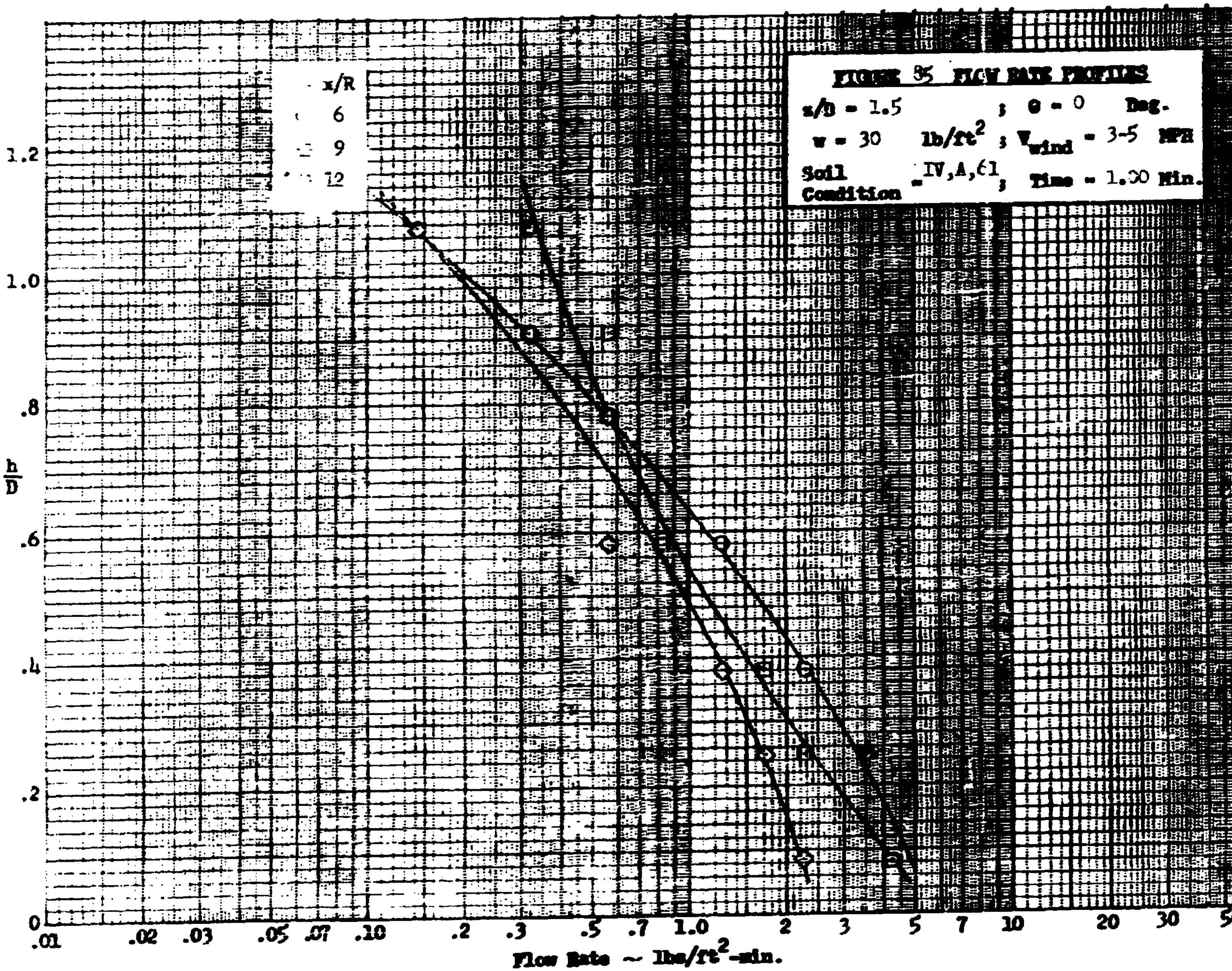


FIGURE 85 FLOW RATE PROFILES

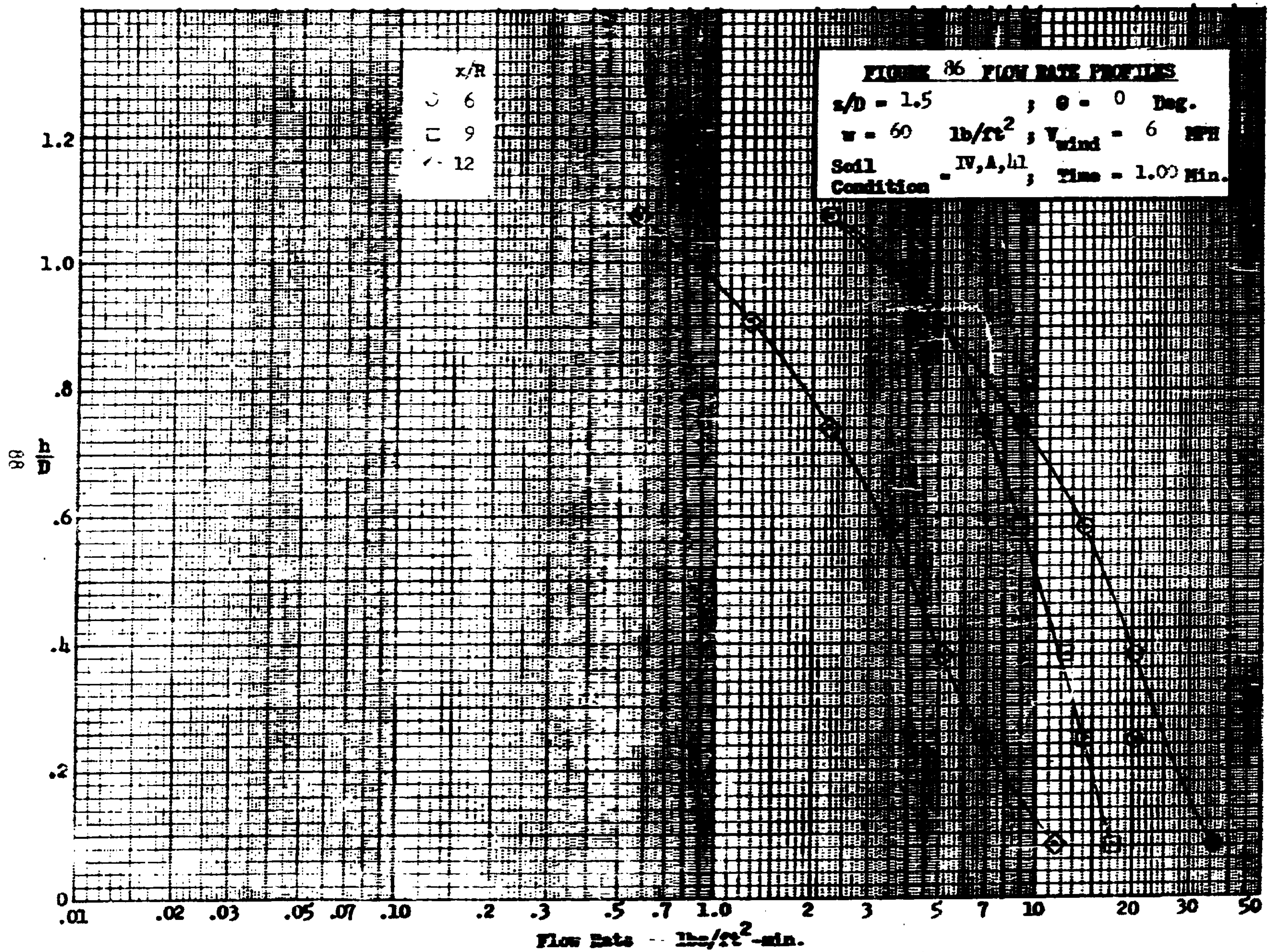


FIGURE 86 FLOW RATE PROFILES
z/D = 1.5 ; Θ = 0 Deg.
w = 60 lb/ft² ; V_wind = 6 MPH
Soil Condition = IV,A,41 ; Time = 1.00 Min.
x/R
○ 6
□ 9
◇ 12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate -- lbs/ft²-min.

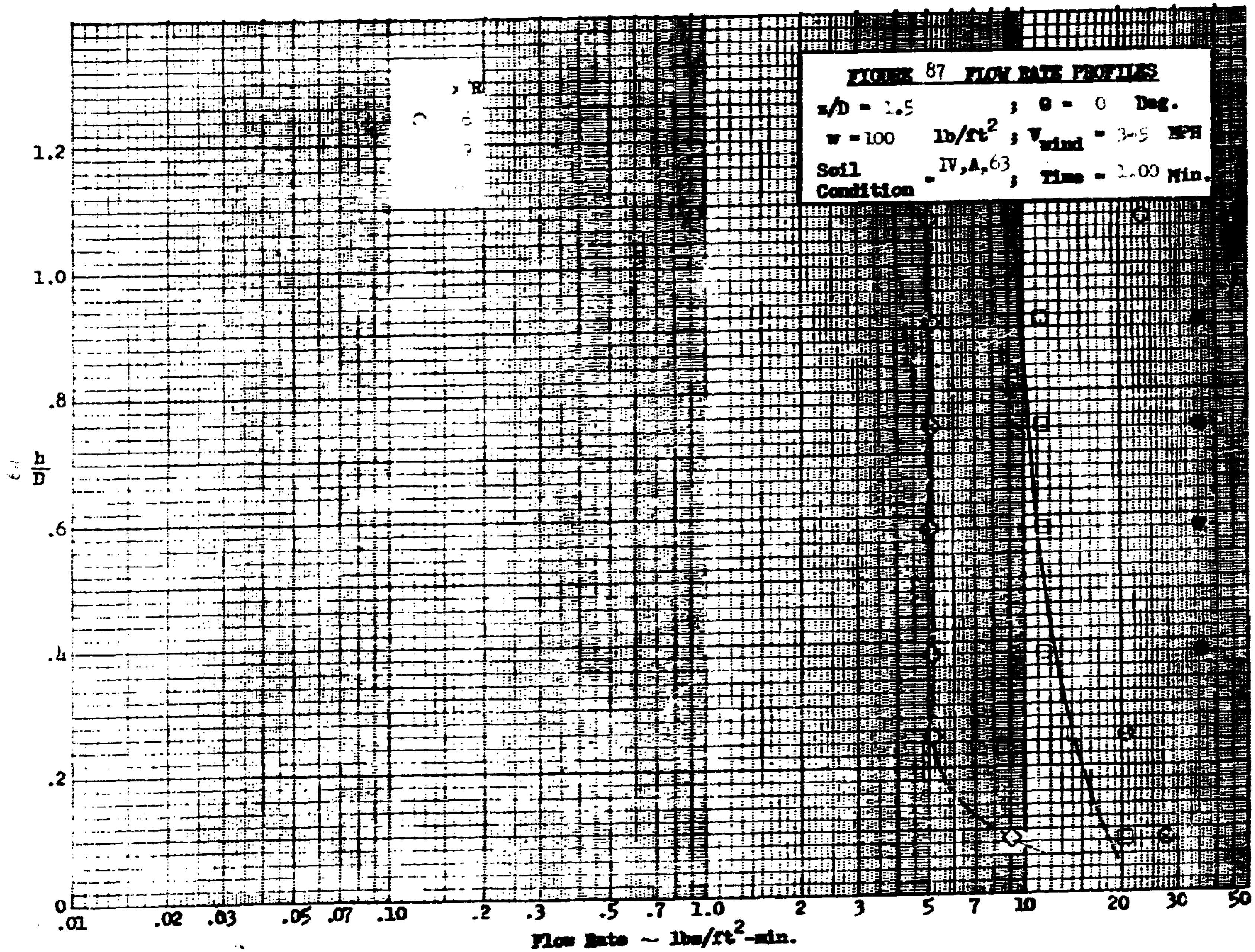


FIGURE 87 FLOW RATE PROFILES
x/D = 1.5 ; Θ = 0 Deg.
w = 100 lb/ft² ; V wind = 3-5 MPH
Soil Condition = IV,A,63 ; Time = 1.00 Min.
h/D
0
.2
.4
.6
.8
1.0
1.2
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

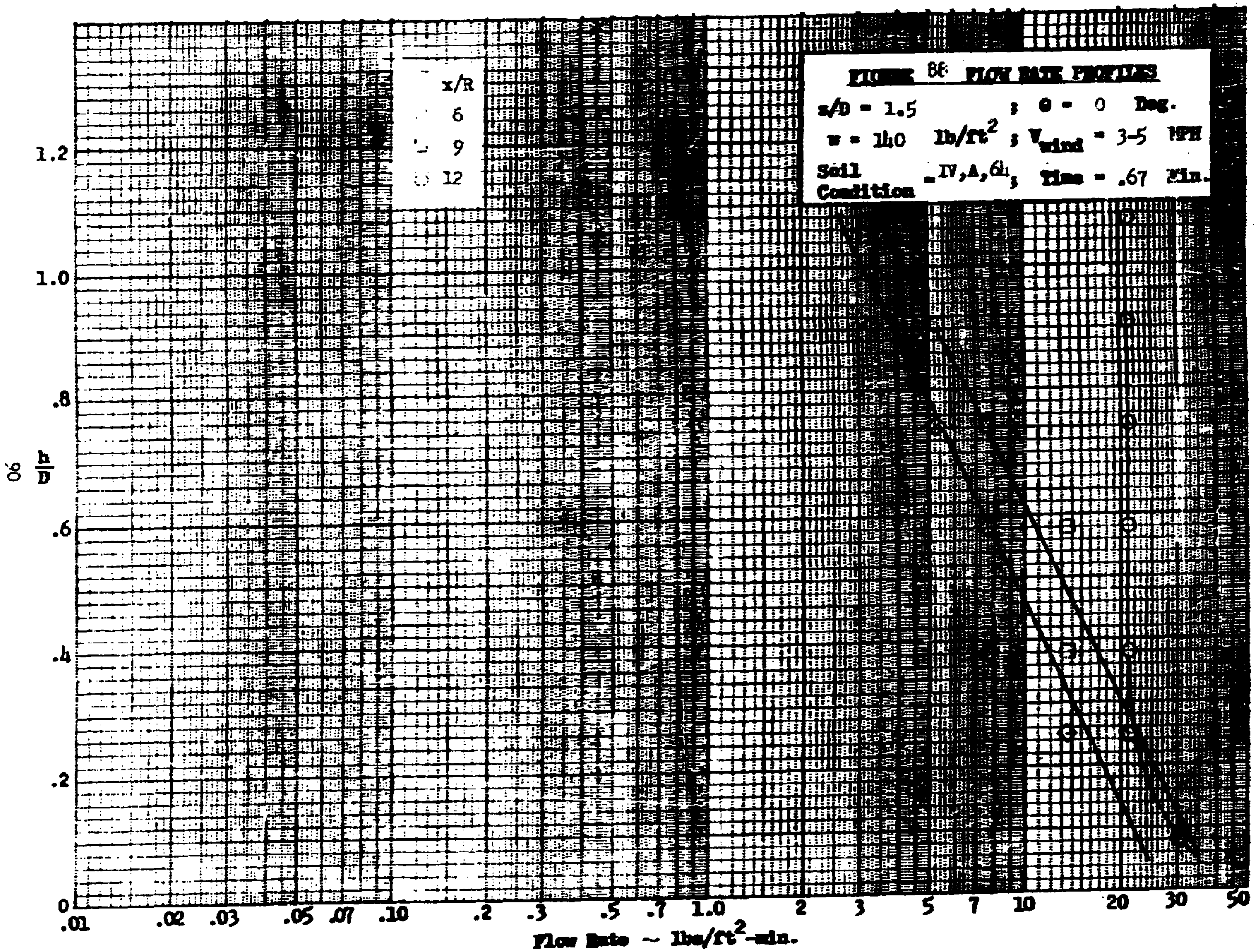


FIGURE 88 FLOW RATE PROFILES
z/D = 1.5 ; θ = 0 Deg.
w = 140 lb/ft² ; V wind = 3-5 MPH
Soil Condition = IV,A,64 ; Time = .67 Min.
x/R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

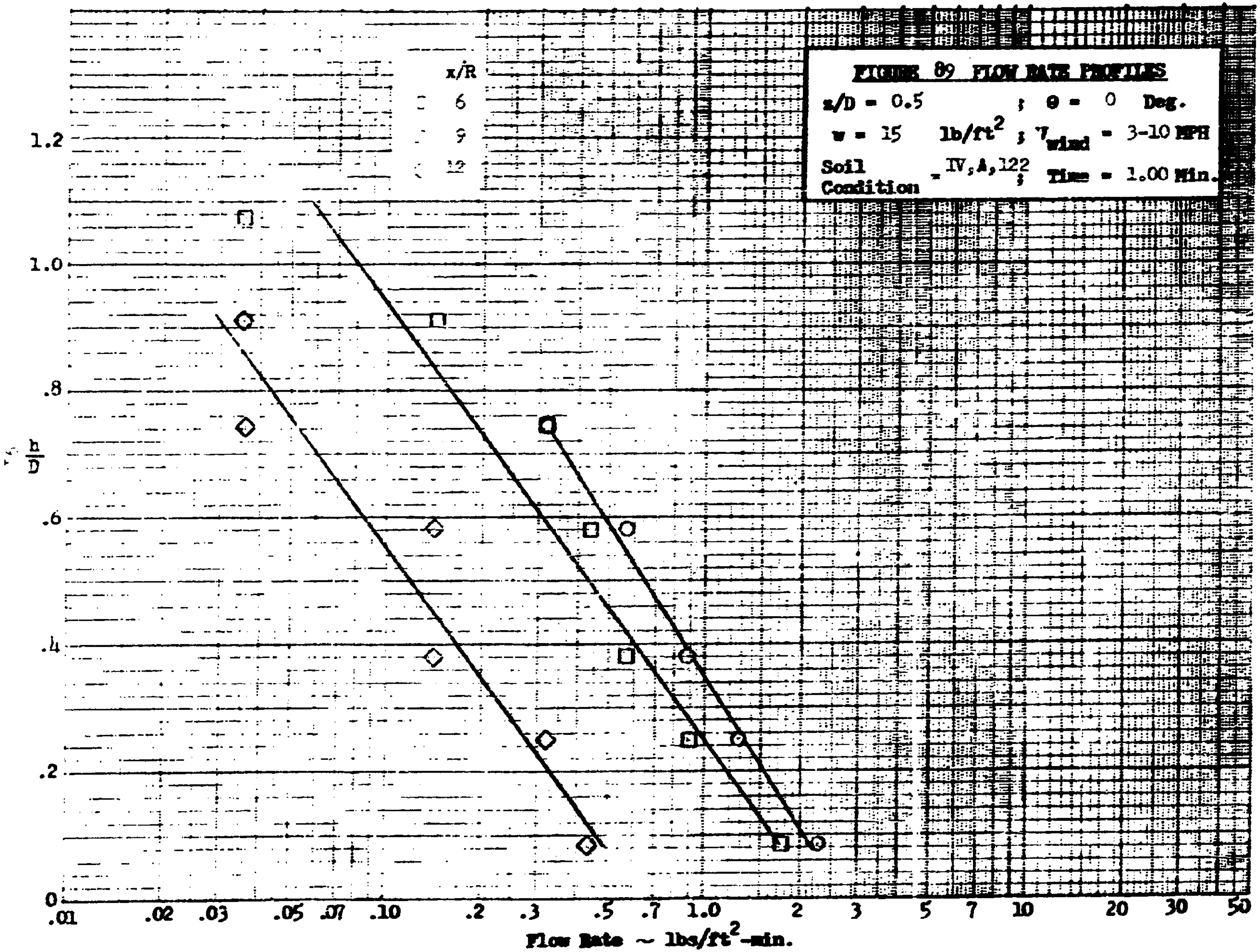


FIGURE 89 FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 15 lb/ft² ; V_wind = 3-10 MPH
Soil Condition = IV, A, 122 ; Time = 1.00 Min.
x/R
6
9
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

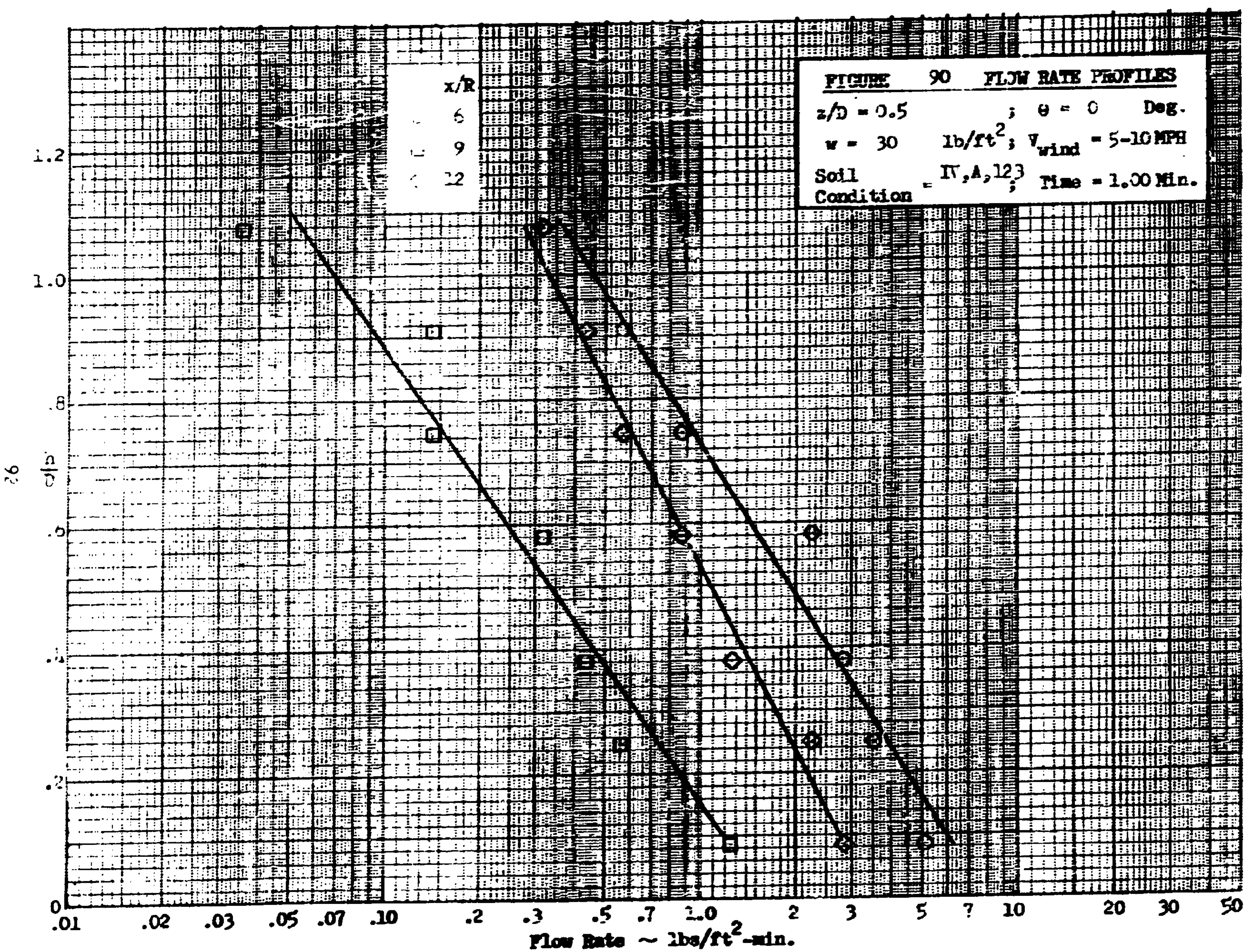


FIGURE 90 FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 30 lb/ft²; V_wind = 5-10 MPH
Soil Condition = IV, A, 123; Time = 1.00 Min.
x/R
6
9
12
1.2
1.0
.8
z/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

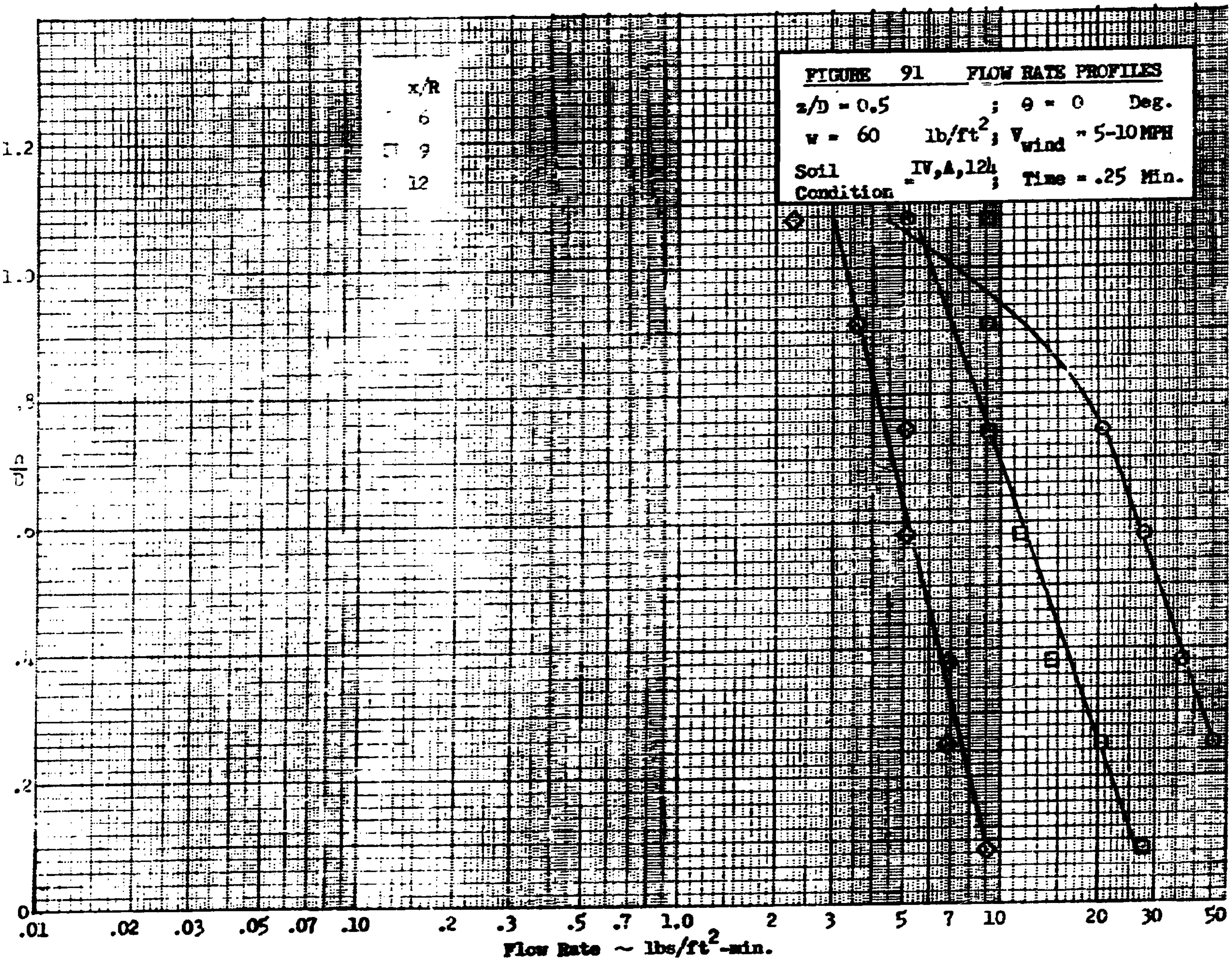


FIGURE 91 FLOW RATE PROFILES
z/D = 0.5 ; θ = 0 Deg.
w = 60 lb/ft²; V wind = 5-10 MPH
Soil Condition = IV,A,12h ; Time = .25 Min.
x/R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
z/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

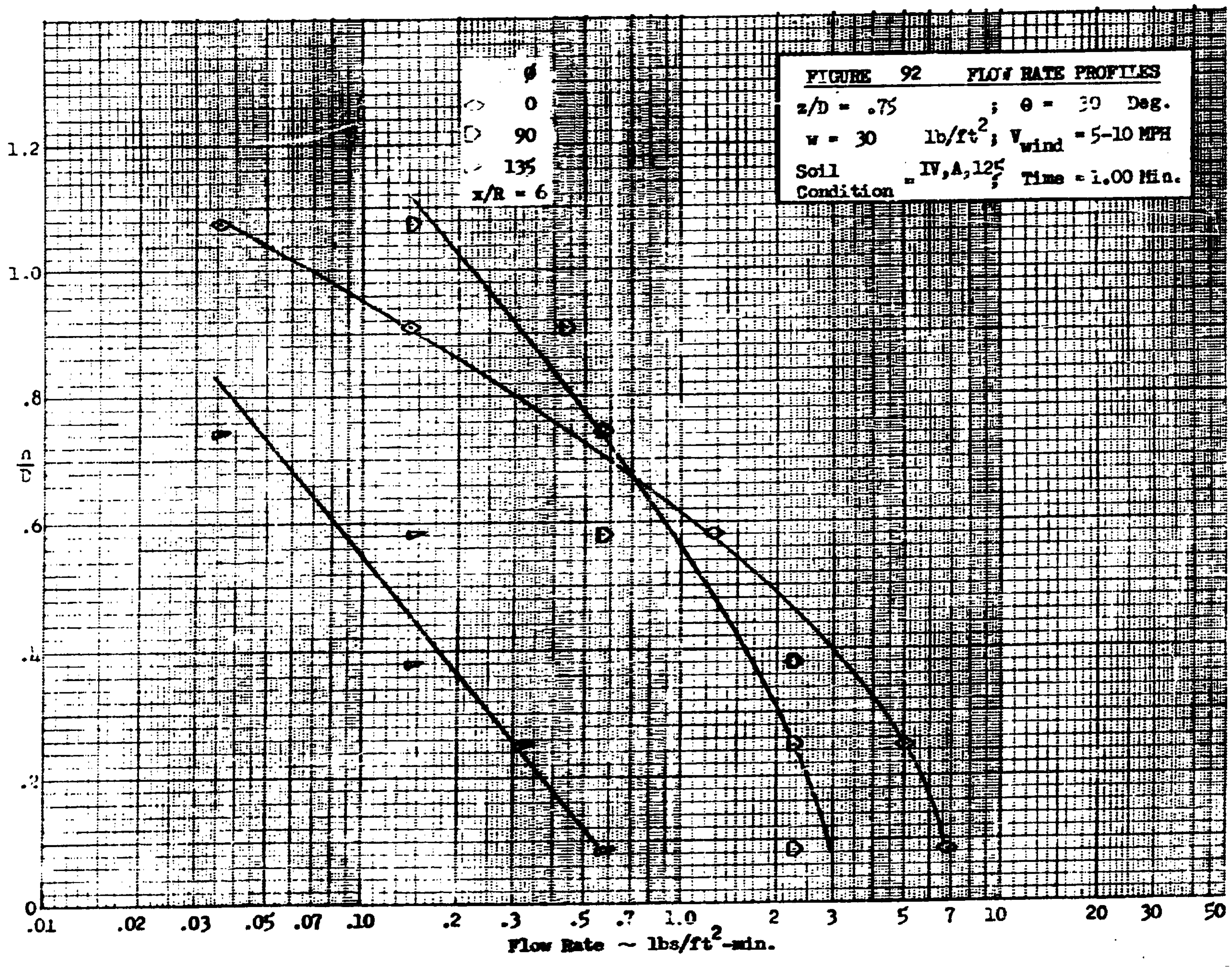


FIGURE 92 FLOW RATE PROFILES
z/D = .75 ; θ = 30 Deg.
w = 30 lb/ft^2; V_{wind} = 5-10 MPH
Soil Condition = IV, A, 125; Time = 1.00 Min.
φ
0
90
135
x/R = 6
1.2
1.0
.8
.6
.4
.2
0
u/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

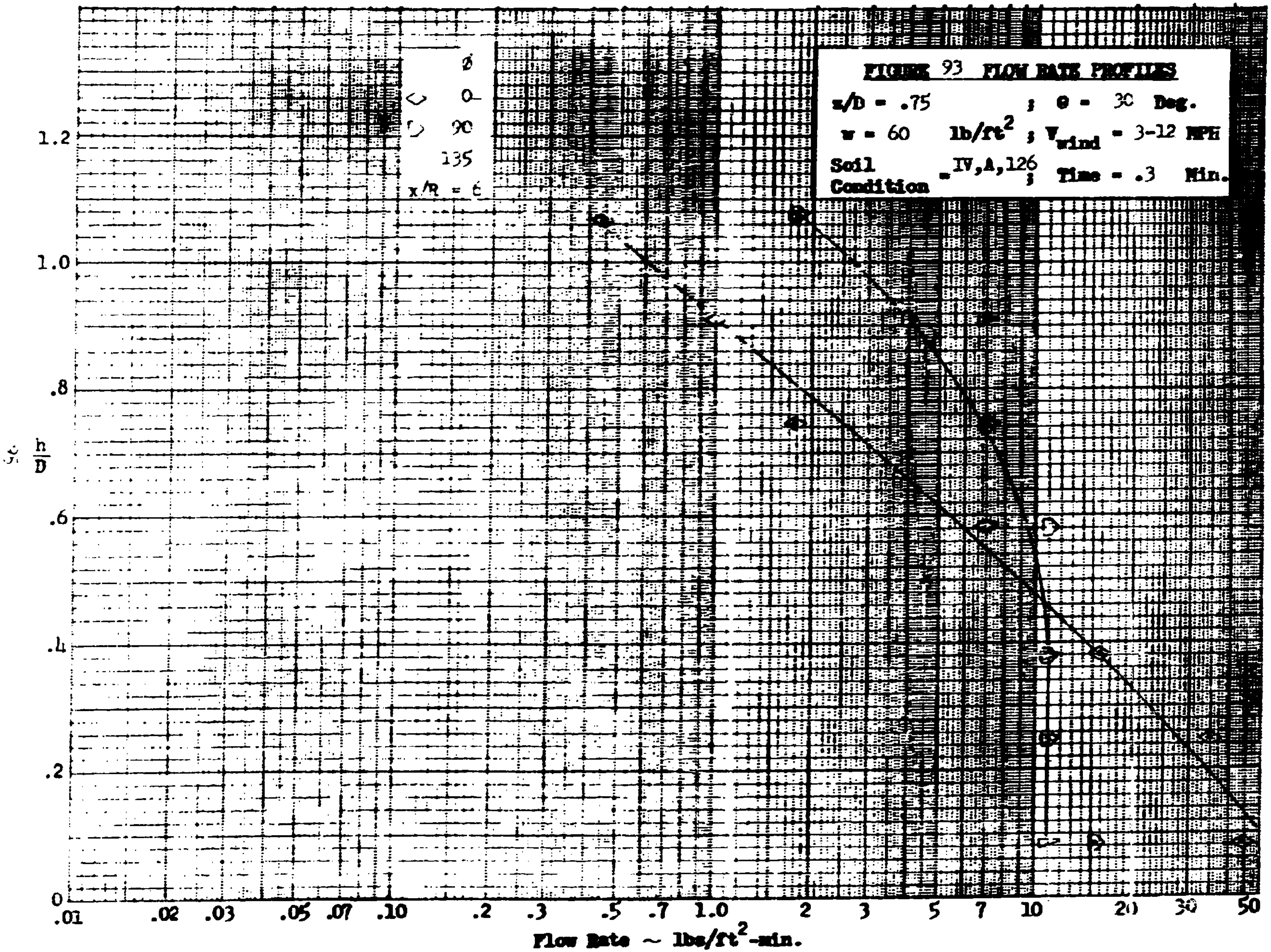


FIGURE 93 FLOW RATE PROFILES
x/D = .75 ; θ = 30 Deg.
w = 60 lb/ft^2 ; V_{wind} = 3-12 MPH
Soil Condition = IV,A,126 ; Time = .3 Min.
ø
0
90
135
x/R = 6
1.2
1.0
.8
.6
.4
.2
0
$\frac{h}{D}$
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

FIGURE 34 RELATIVE DIAMETER OF HEATED SECTION

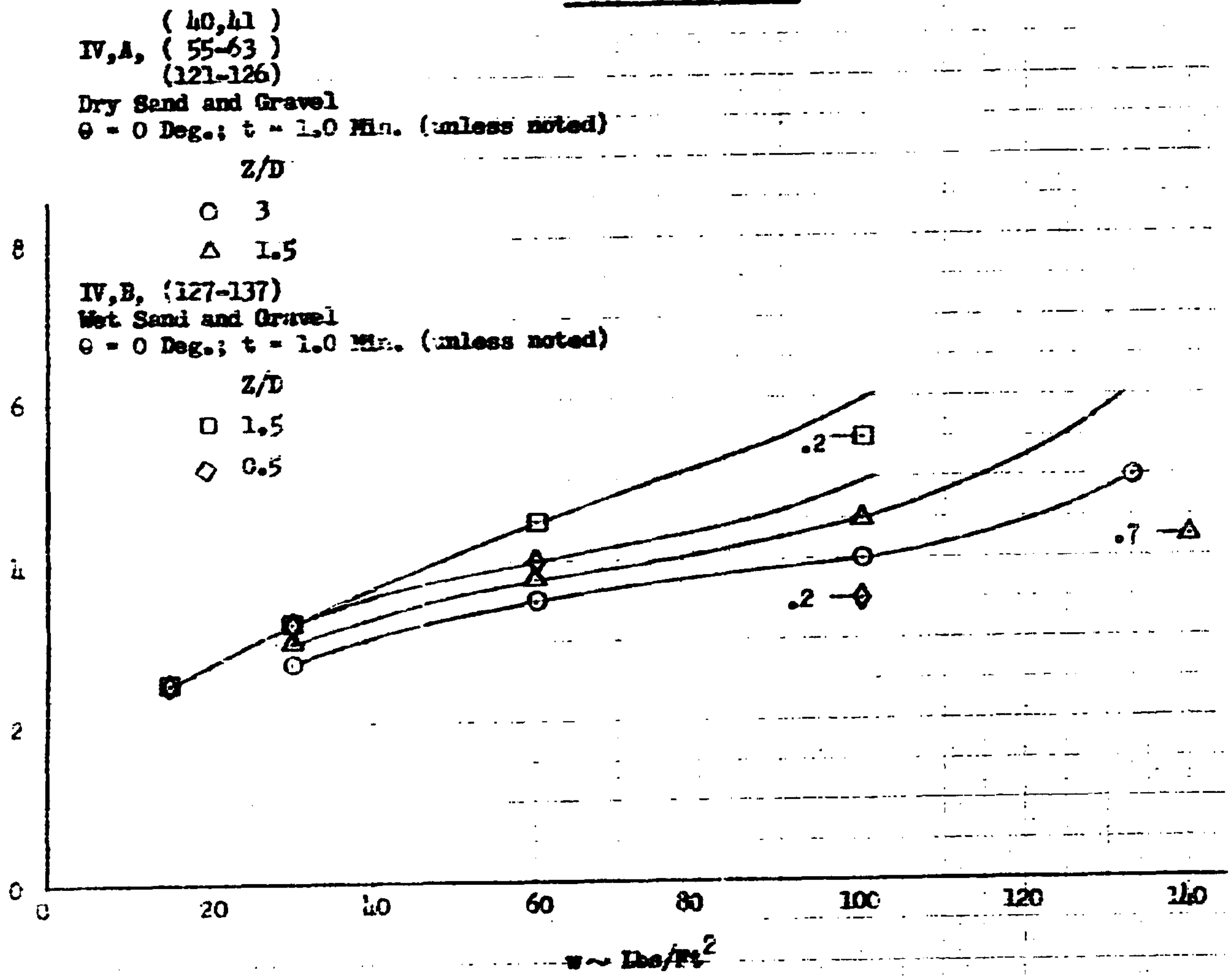


FIGURE 95 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 15, θ = 0

IV-A55

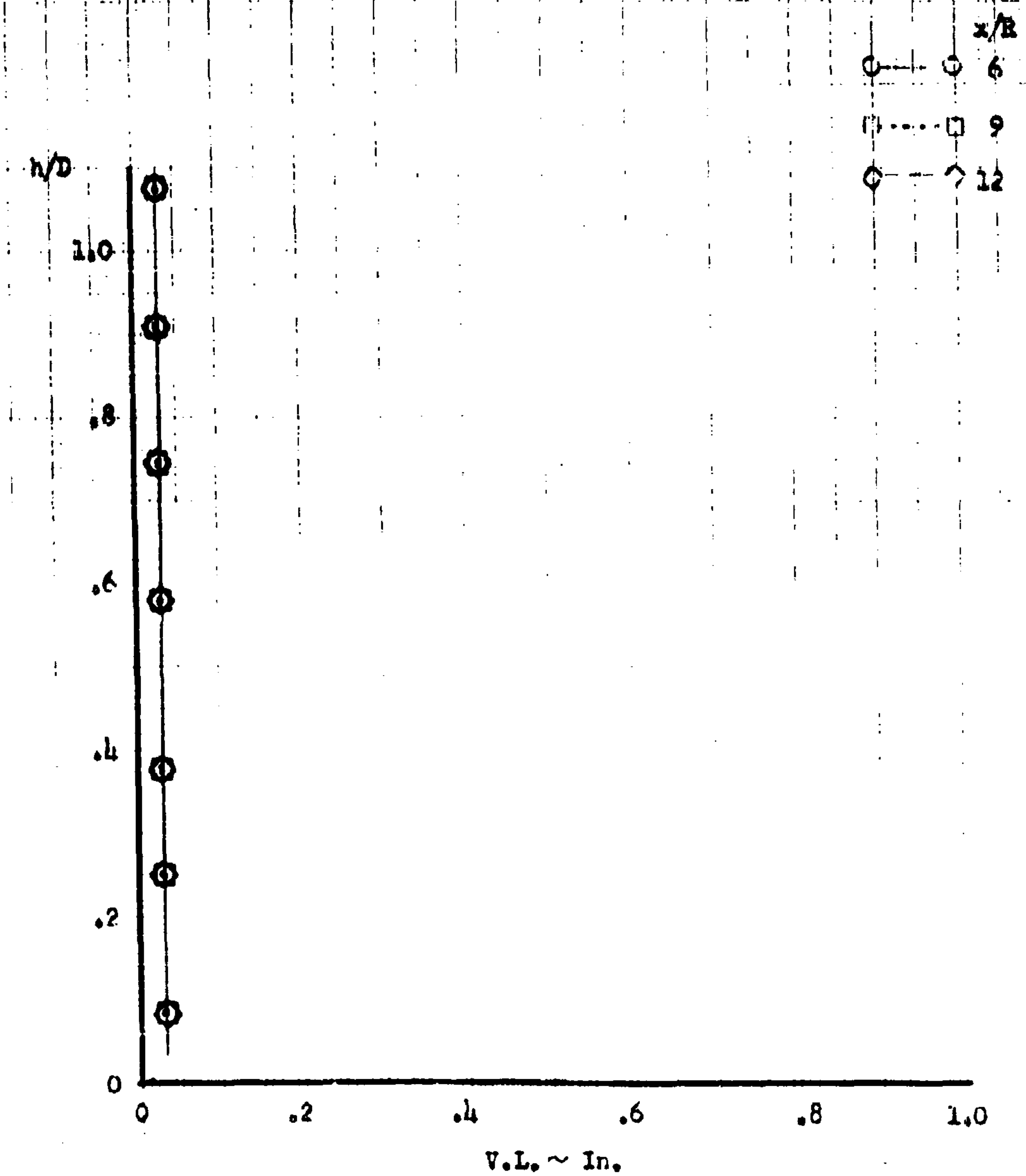


FIGURE 96 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 30, θ = 0

IV-A56

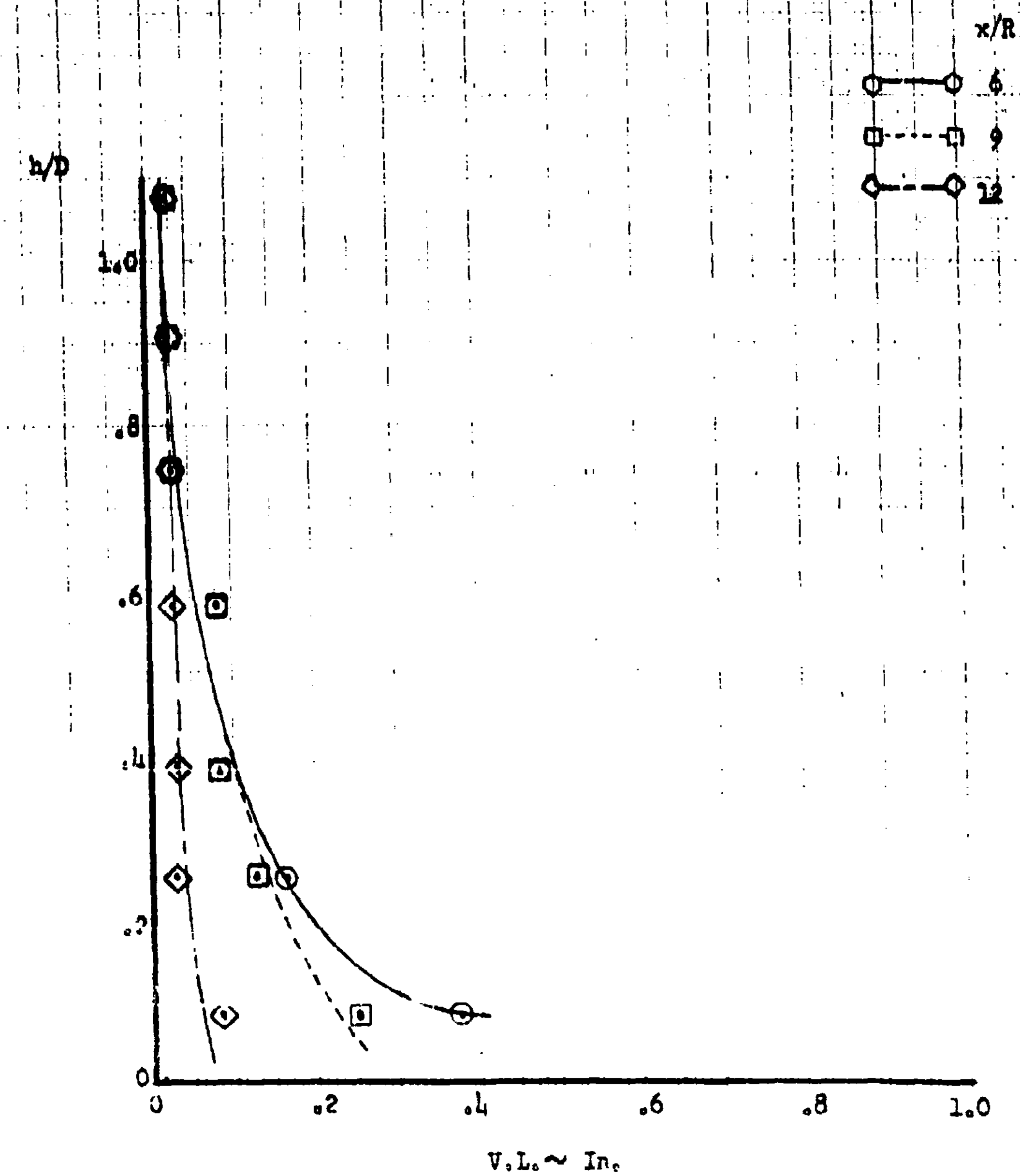


FIGURE 97 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 60, θ = 0

IV-A57

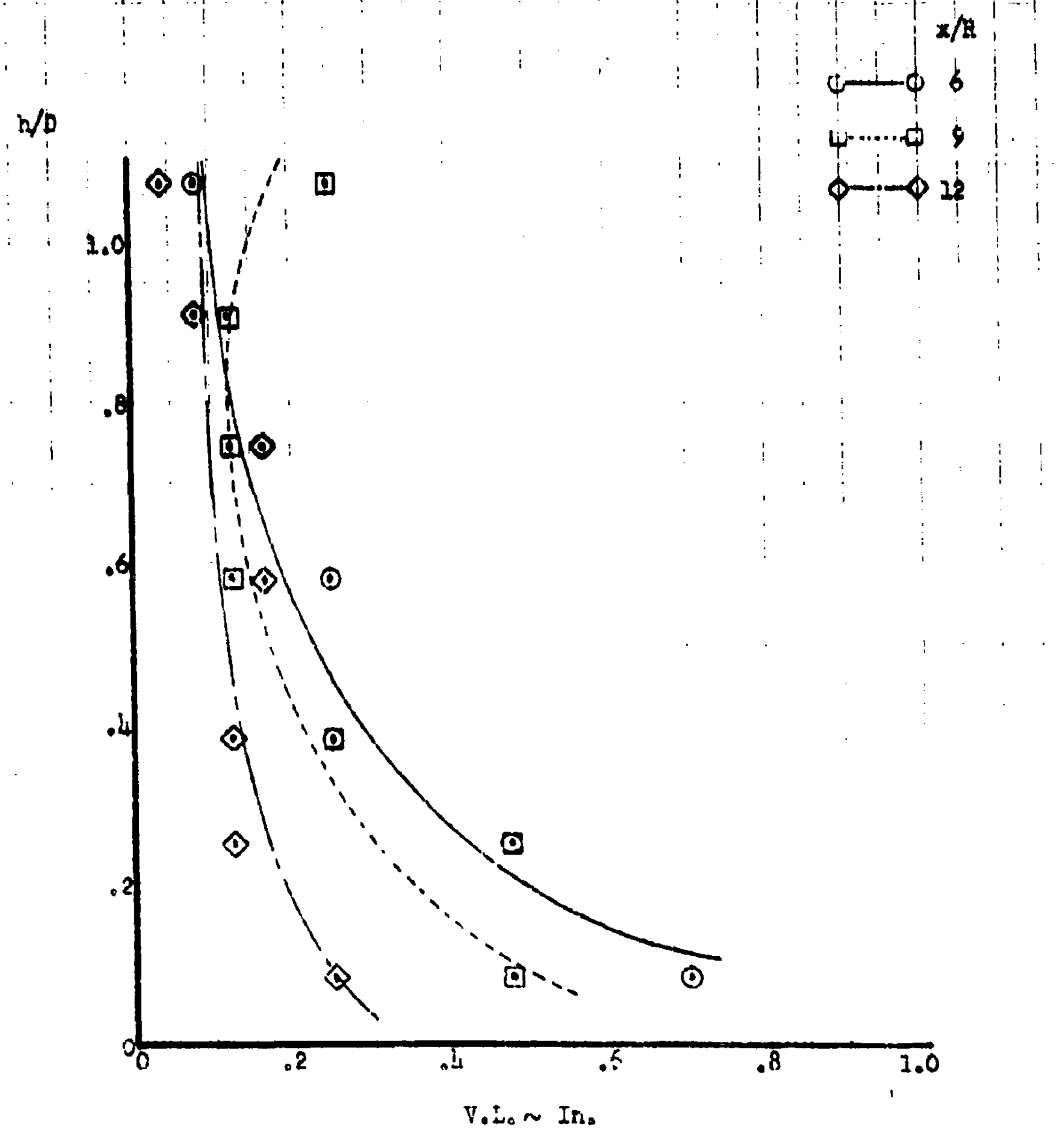


FIGURE 98 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 100, θ = 0

IV-A58

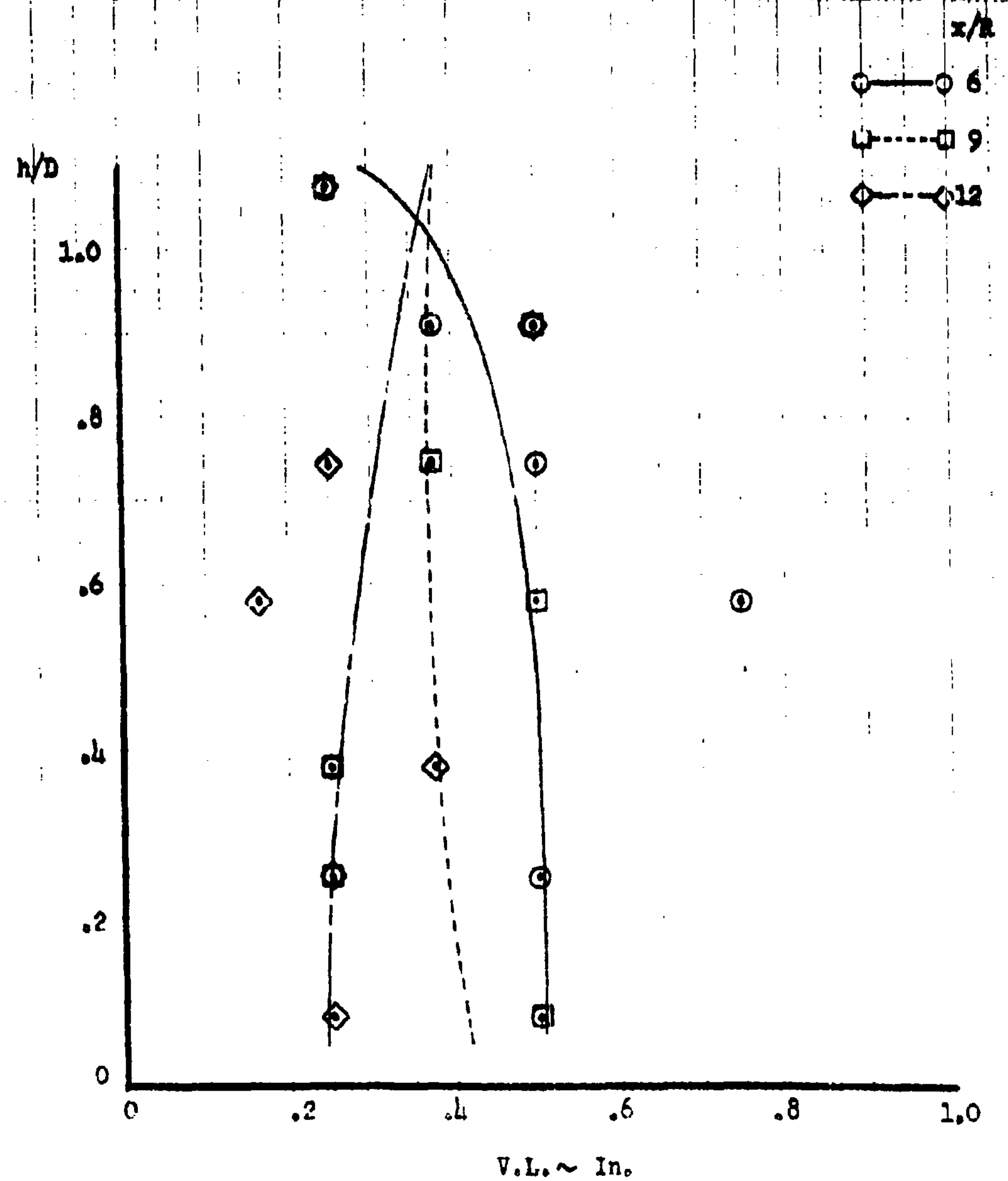


FIGURE 99 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 133, θ = 0

IV-A59

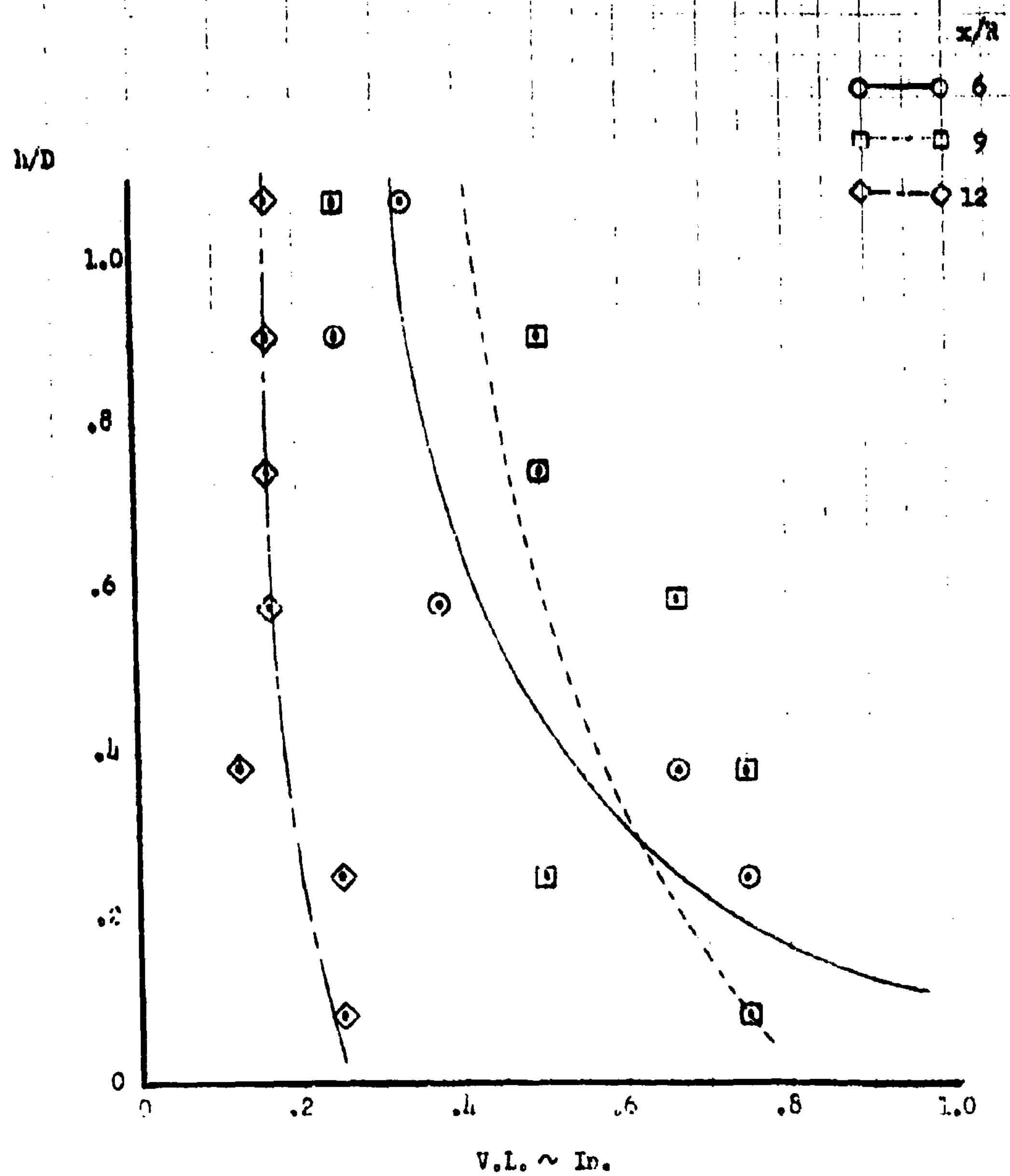
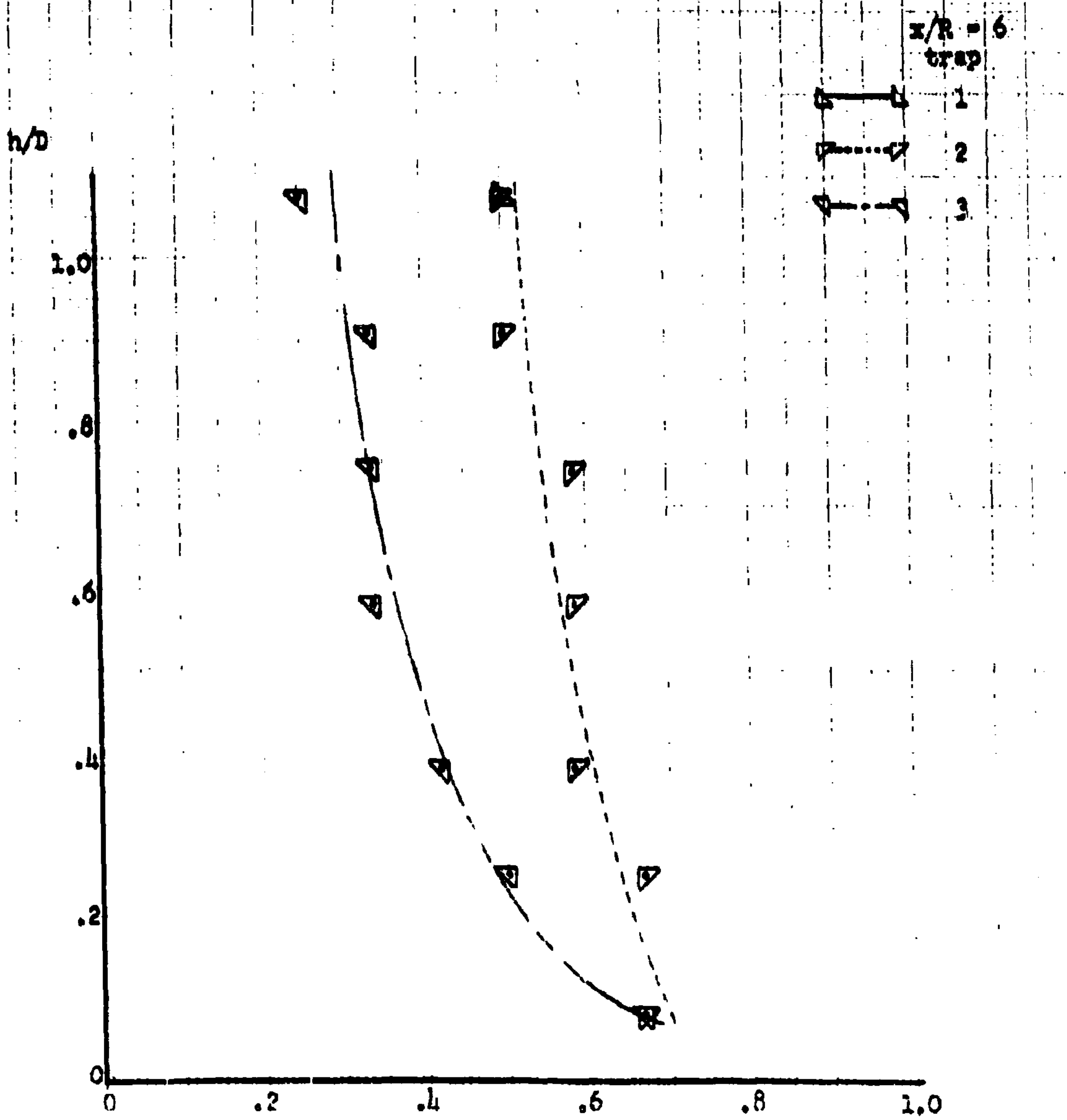


FIGURE 10 CORRELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = var., θ = 0

IV-A40



Largest Particle Volume / Area V.L. ~ In.

FIGURE 101 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = 15, θ = 0

IV-A60

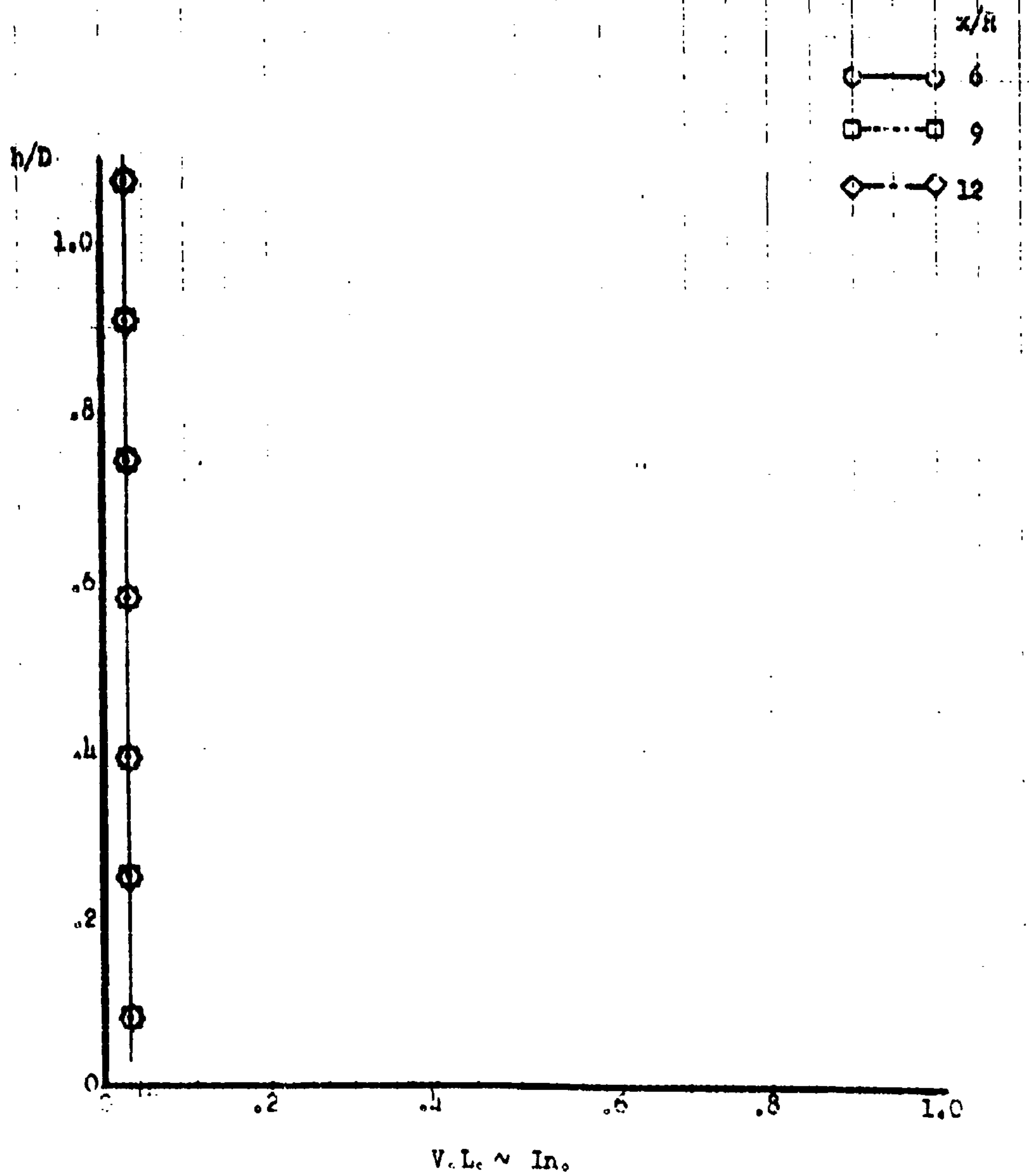


FIGURE 102 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

$Z/D = 1.5,\ w = 30,\ \theta = 0$

IV-A61

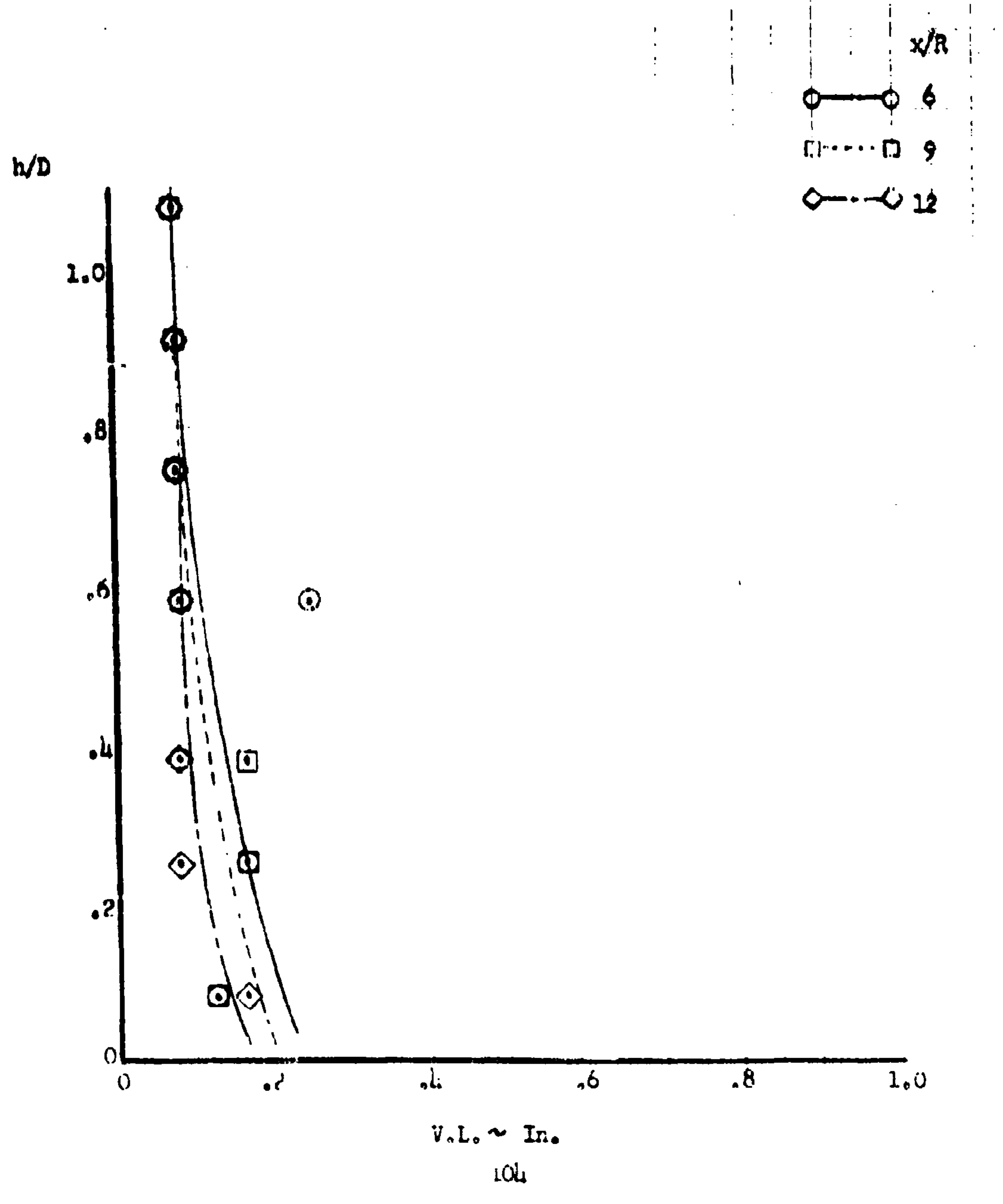


FIGURE 103 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = 60, θ = 0

IV-A41

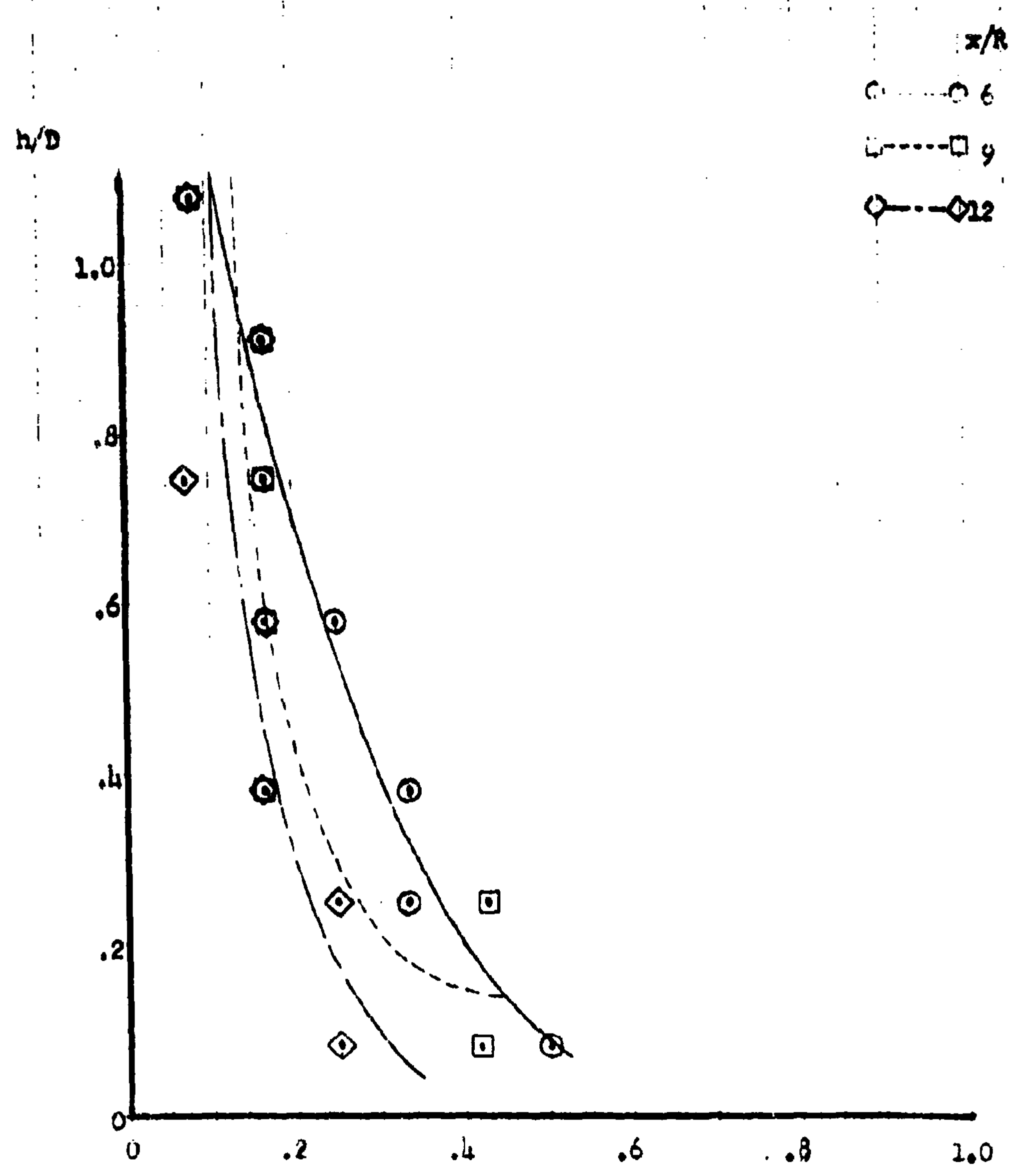


FIGURE 104 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = 100, θ = 0

IV-A62

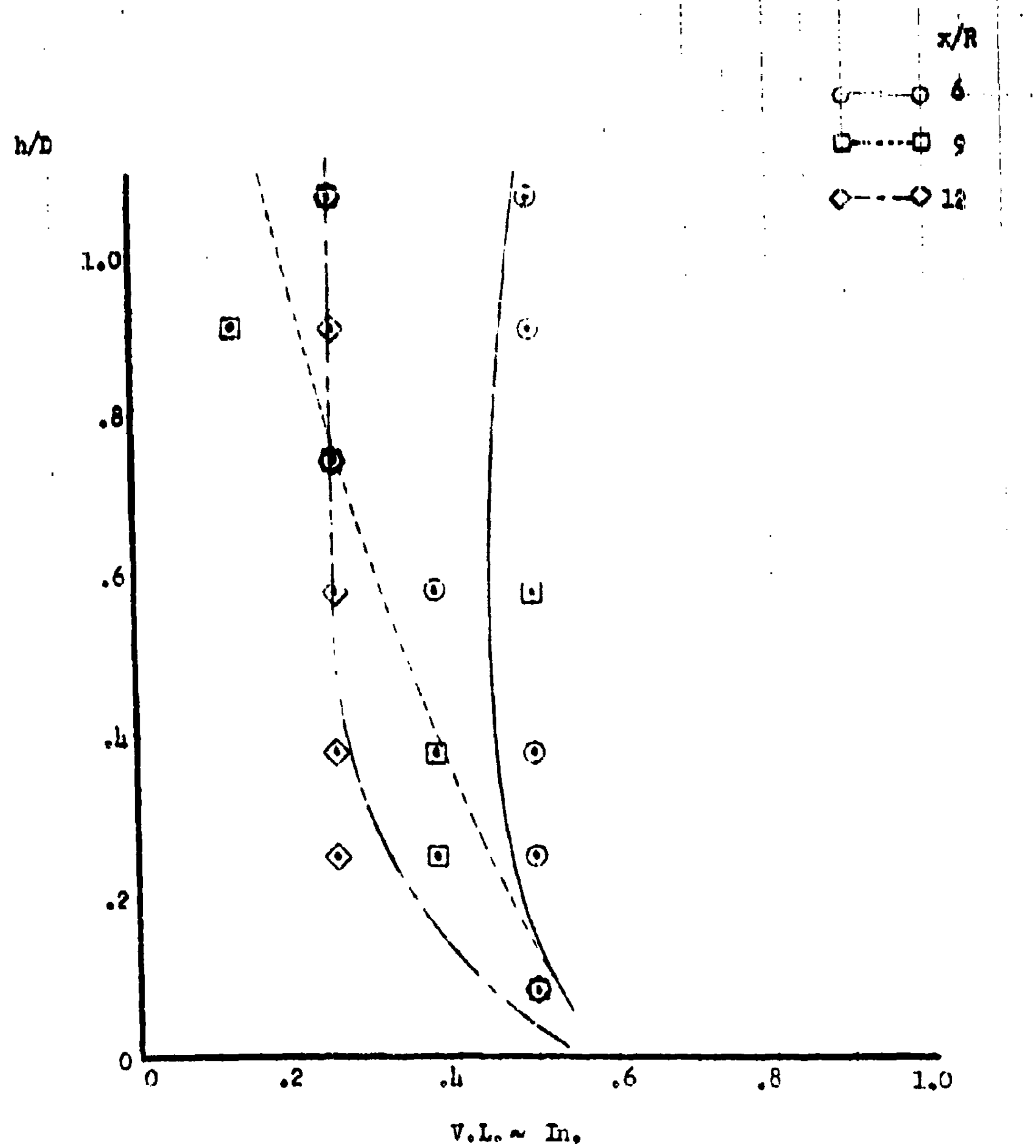


FIGURE 105 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = 140, θ = 0

IV-A63

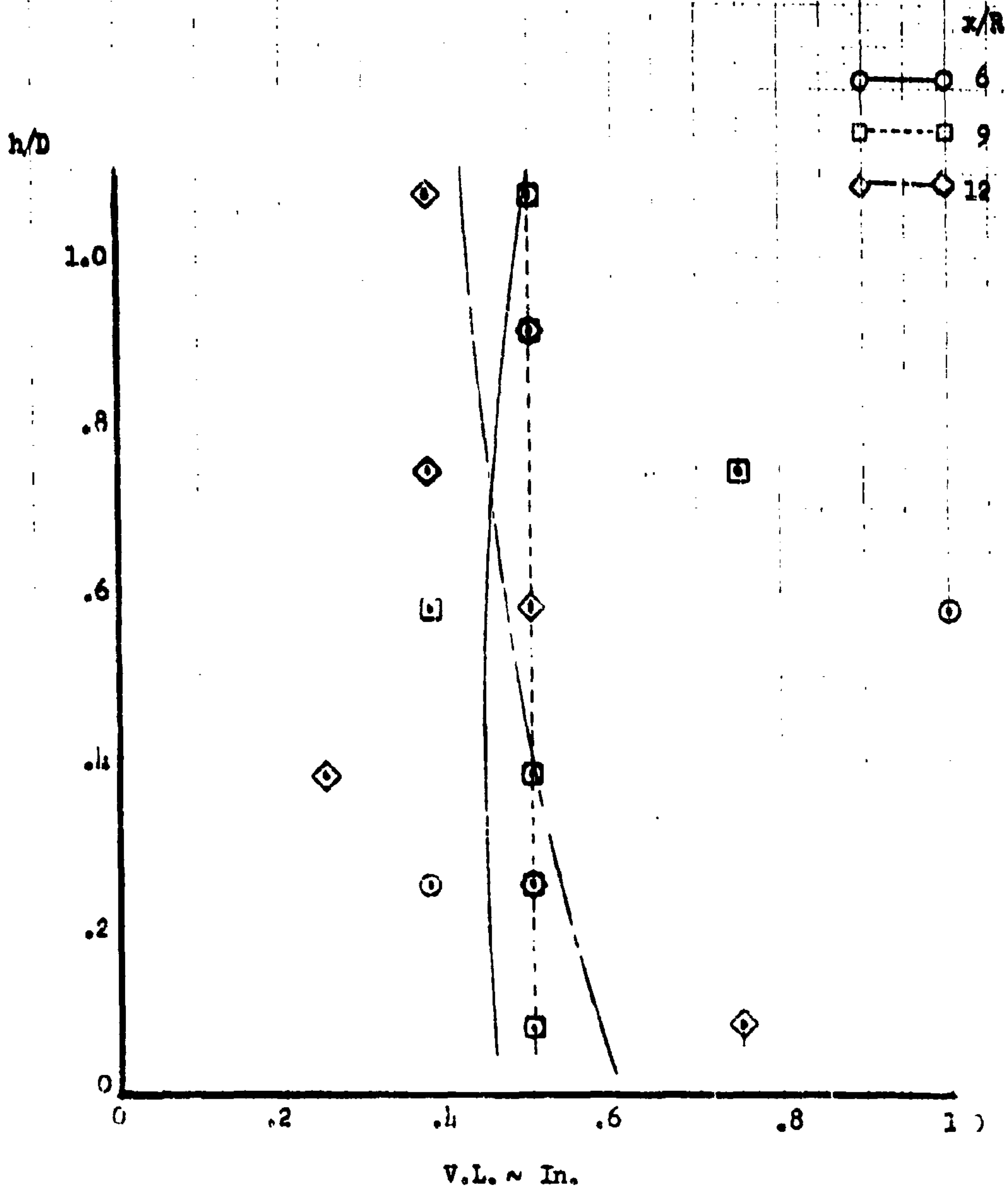


FIGURE 106 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = .5, w = 15, θ = 0

IV-A122

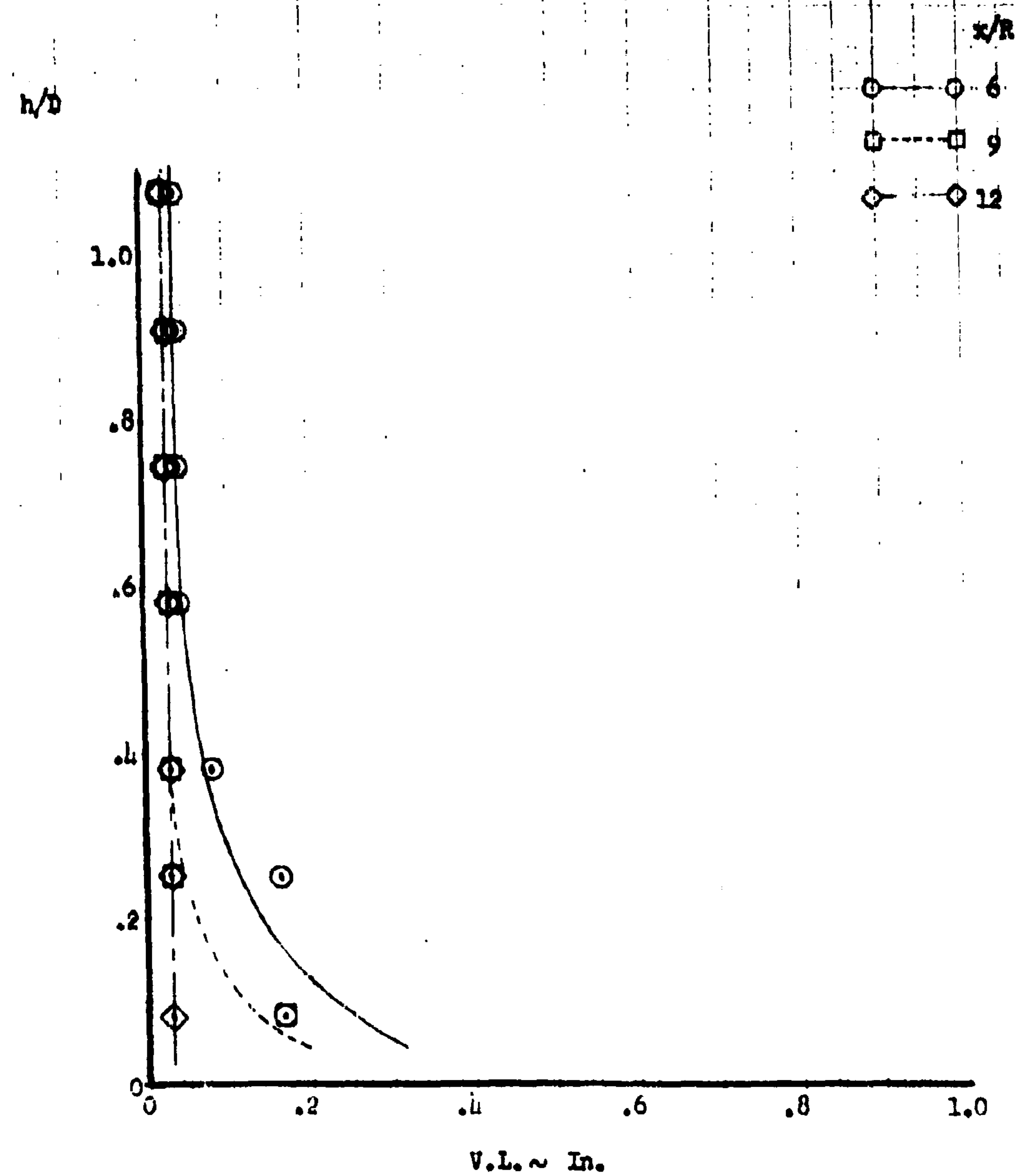


FIGURE 107 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = .5, ψ = 30, θ = 0

IV-A123

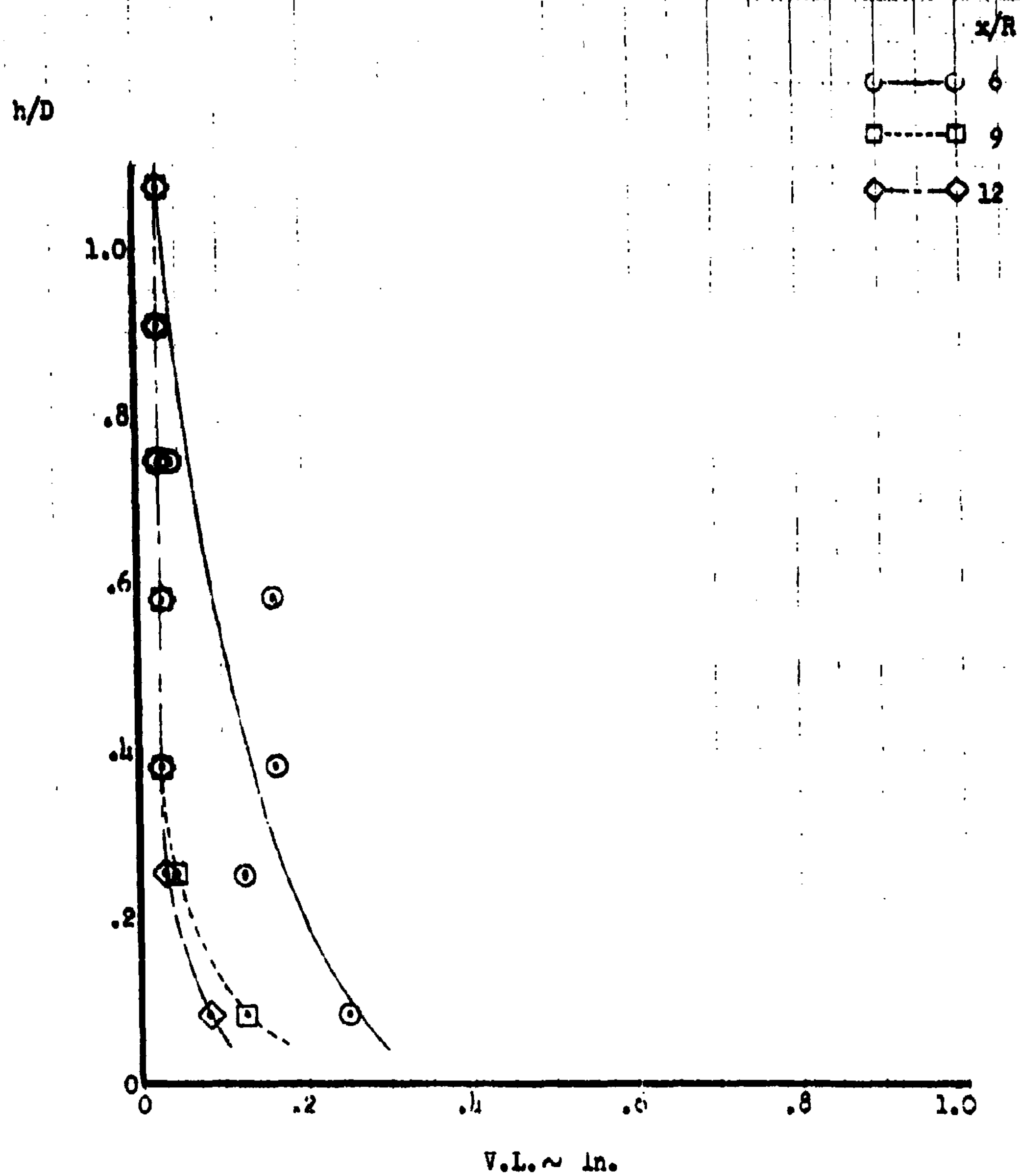
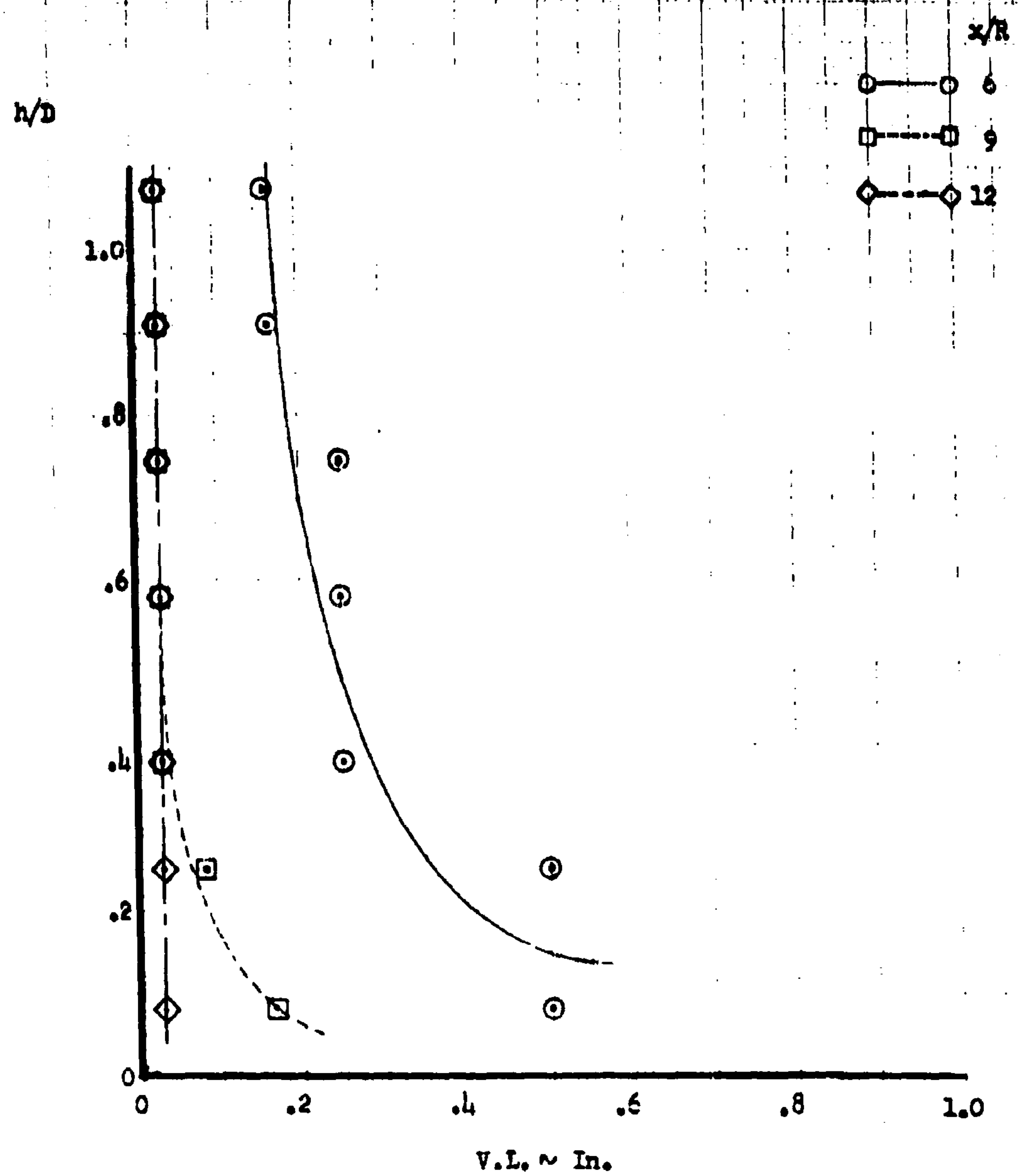


FIGURE 108 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = .5, w = 60, φ = 0

IV-A124



F-12D

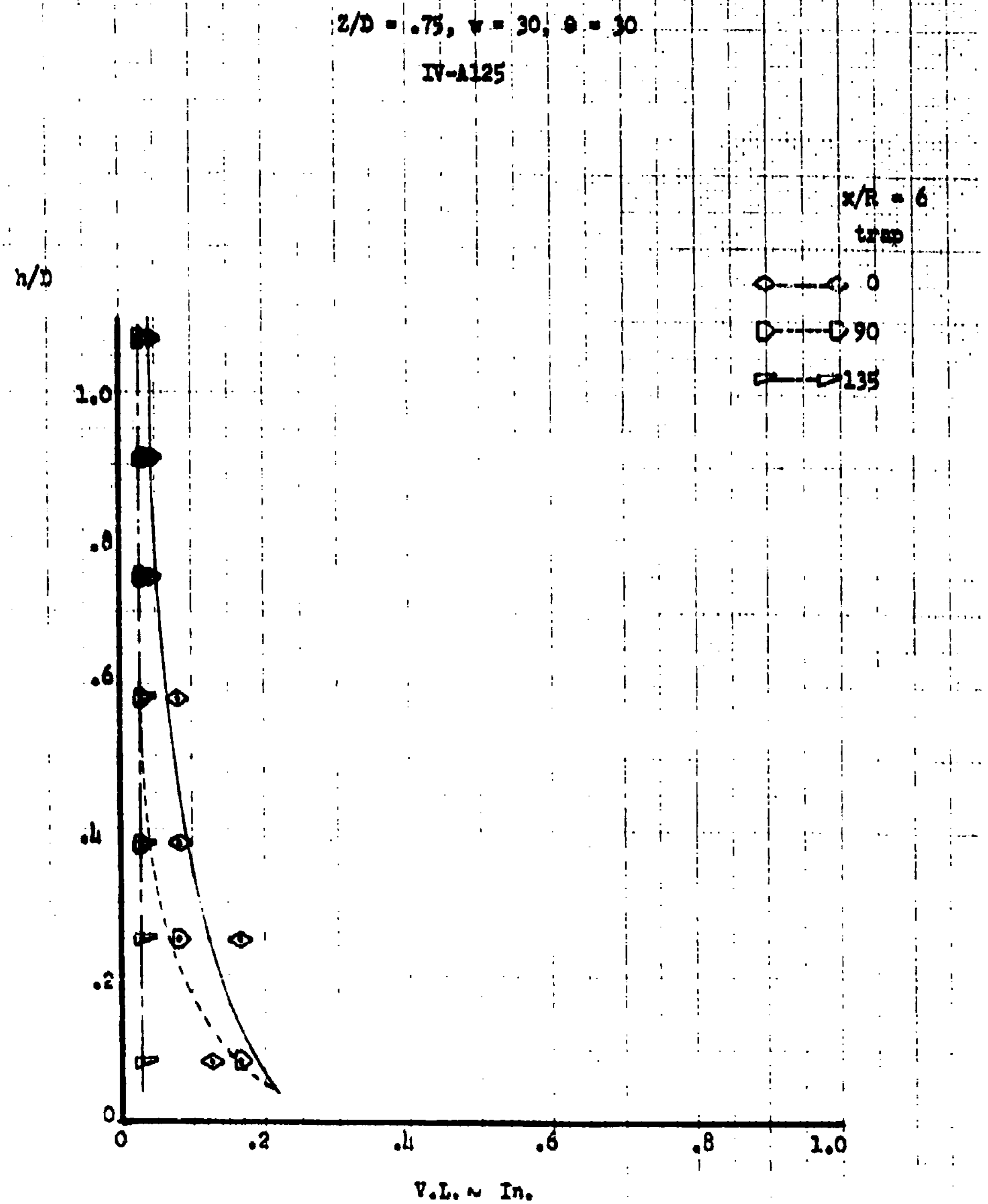
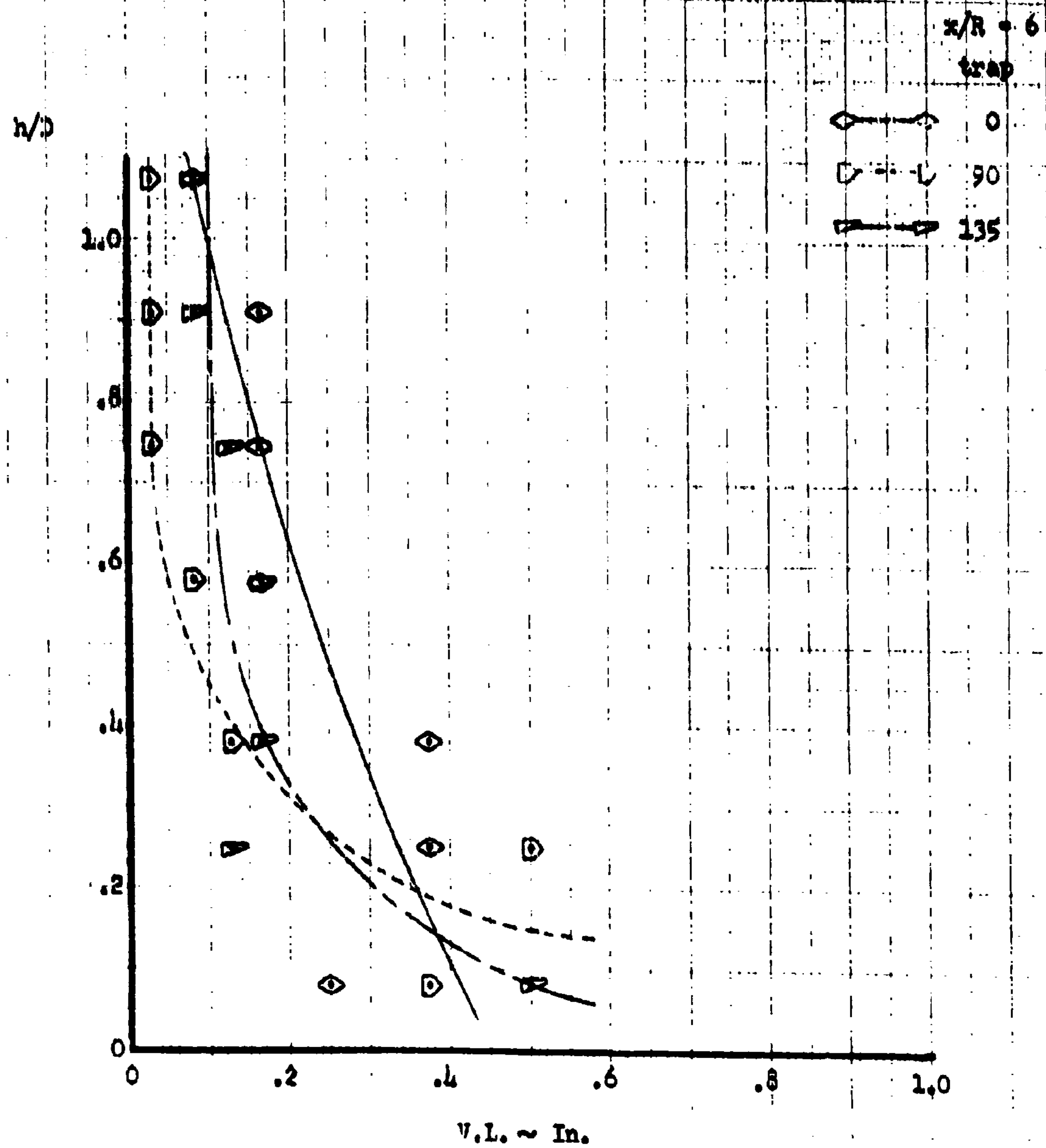


FIGURE 109 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

FIGURE 110 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = .75, w = 60, θ = 30

IV-A126



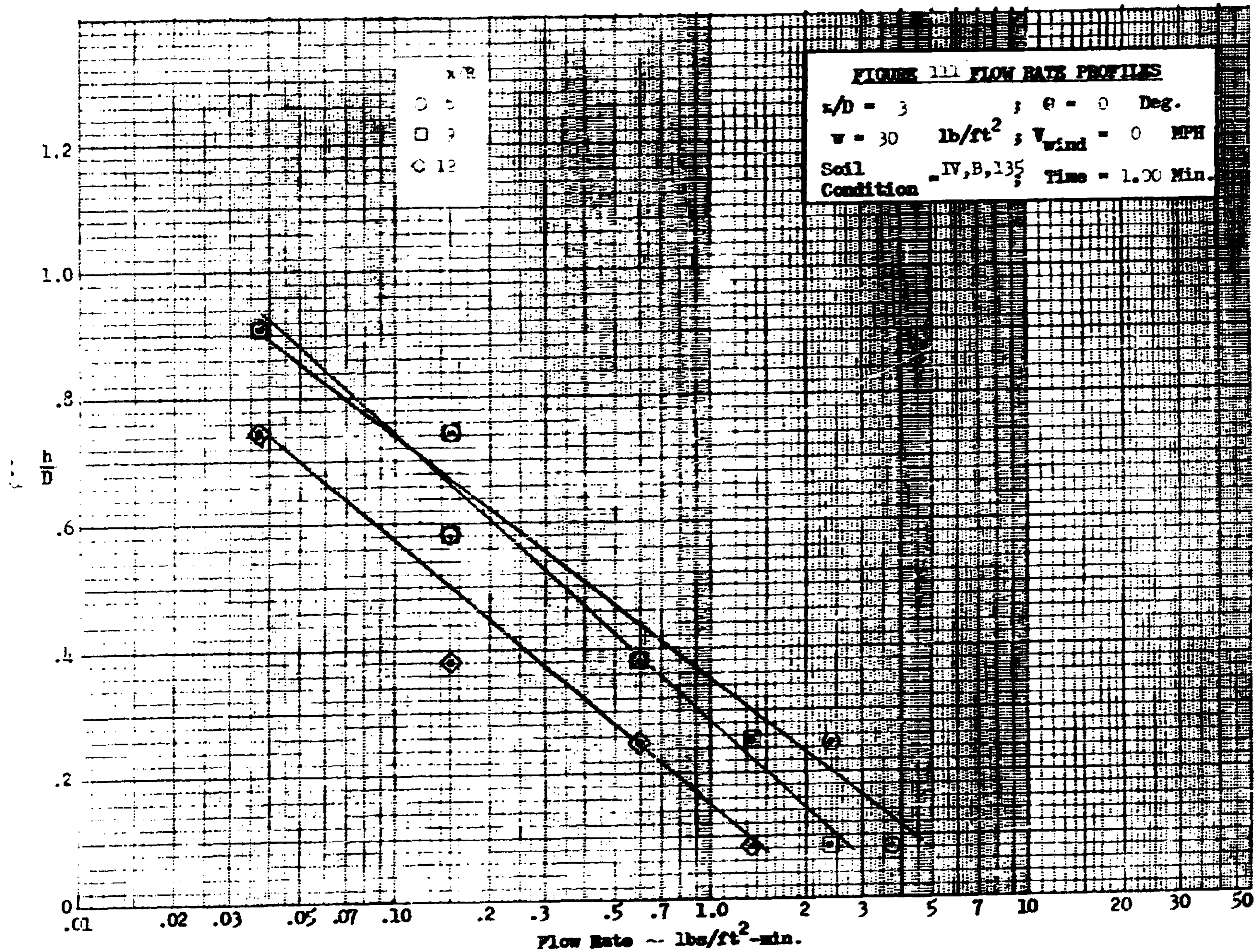


FIGURE 111 FLOW RATE PROFILES
x/D = 3 ; θ = 0 Deg.
w = 30 lb/ft^2 ; V_{wind} = 0 MPH
Soil Condition = IV,B,135 ; Time = 1.00 Min.
x/B
12
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

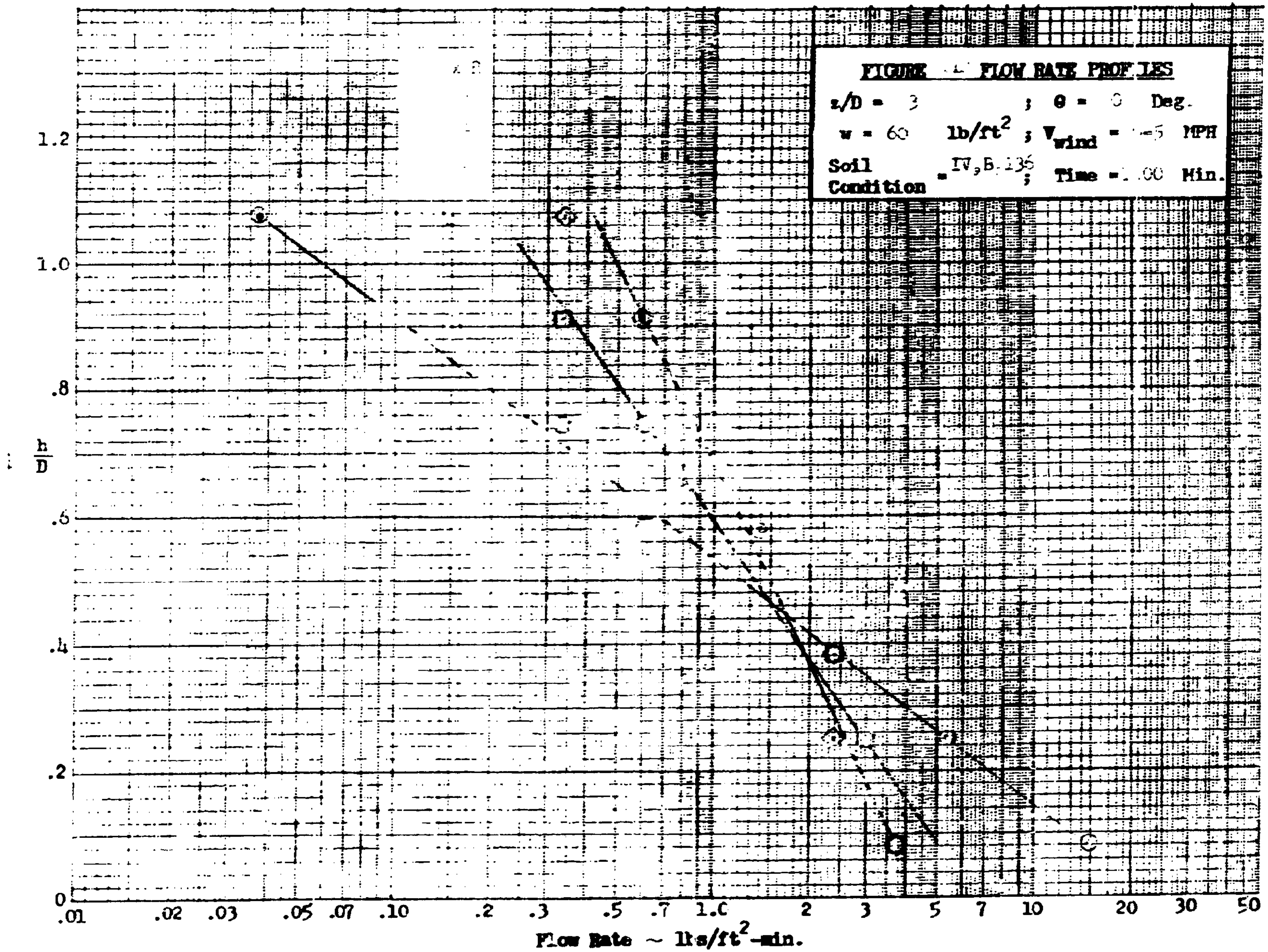


FIGURE FLOW RATE PROFILES
z/D = 3 ; θ = 0 Deg.
w = 60 lb/ft² ; V wind = MPH
Soil Condition = IV, B.136 ; Time = .00 Min.
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

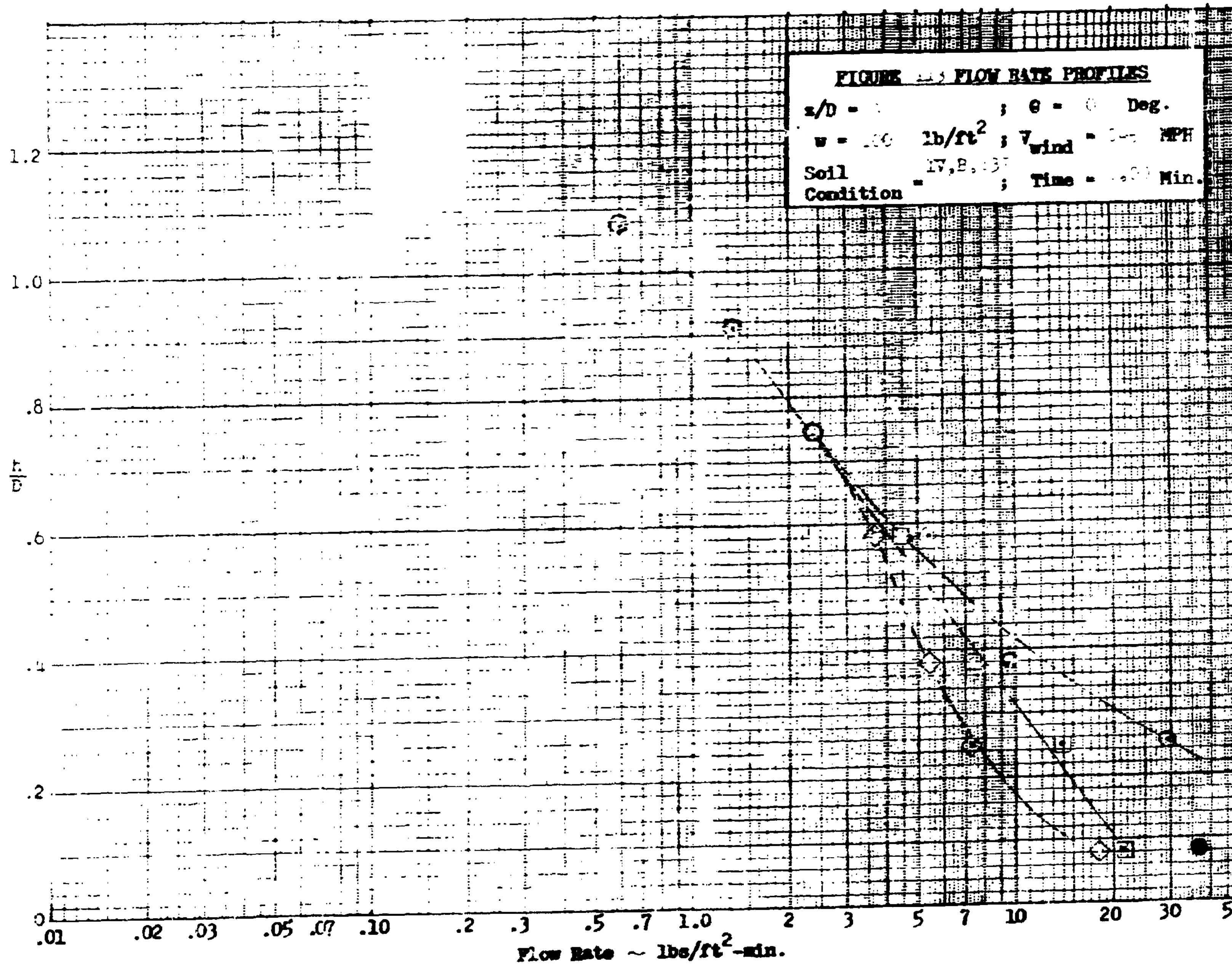


FIGURE FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft²; V_{wind} = MPH
Soil Condition = ; Time = Min.
1.2
1.0
.8
h/D
.6
.4
.2
0
.01 .02 .03 .05 .07 .10 .2 .3 .5 .7 1.0 2 3 5 7 10 20 30 50
Flow Rate ~ lbs/ft²-min.

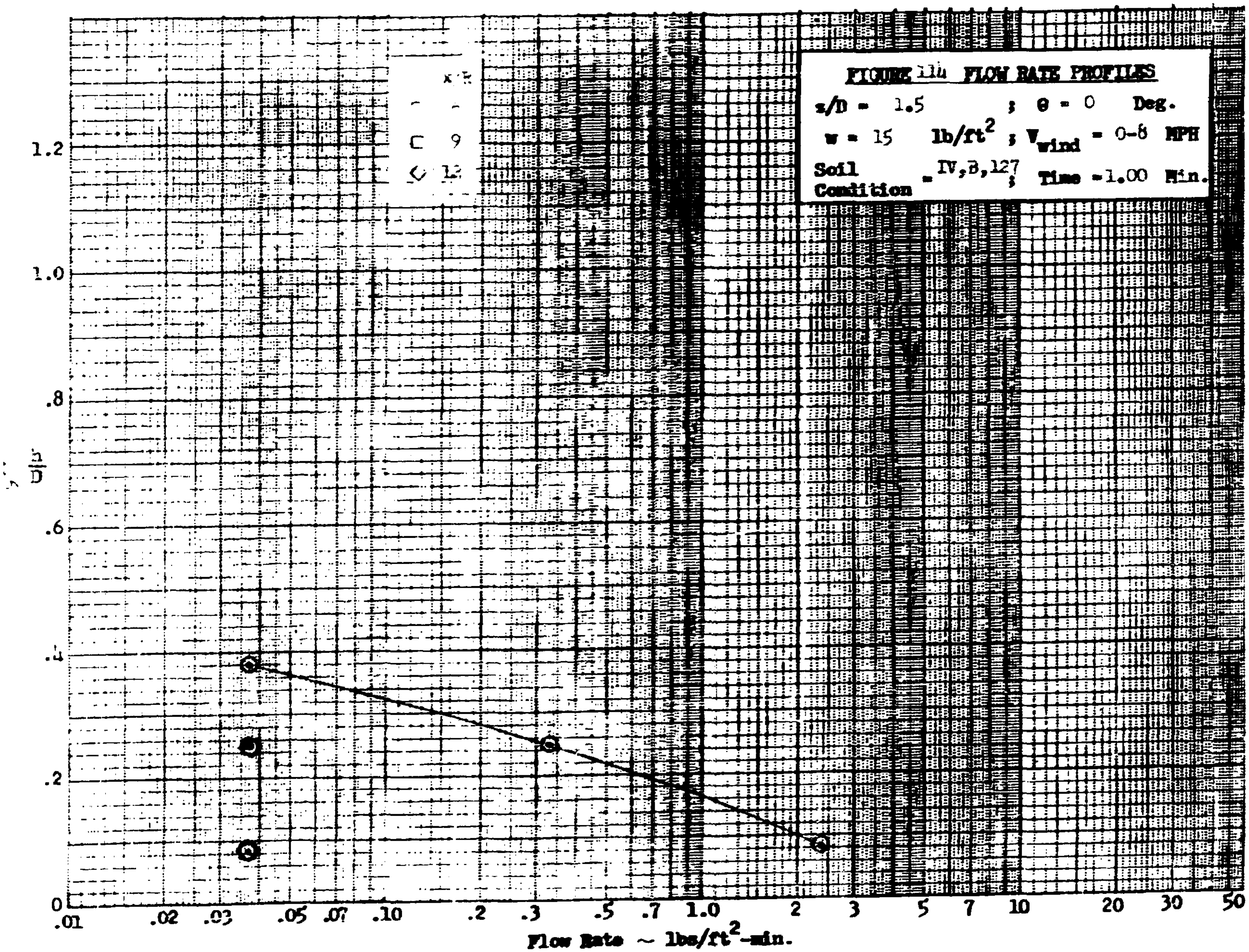


FIGURE 114 FLOW RATE PROFILES
s/D = 1.5 ; θ = 0 Deg.
w = 15 lb/ft² ; V wind = 0-8 MPH
Soil Condition = IV,B,127 ; Time = 1.00 Min.
x/R
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

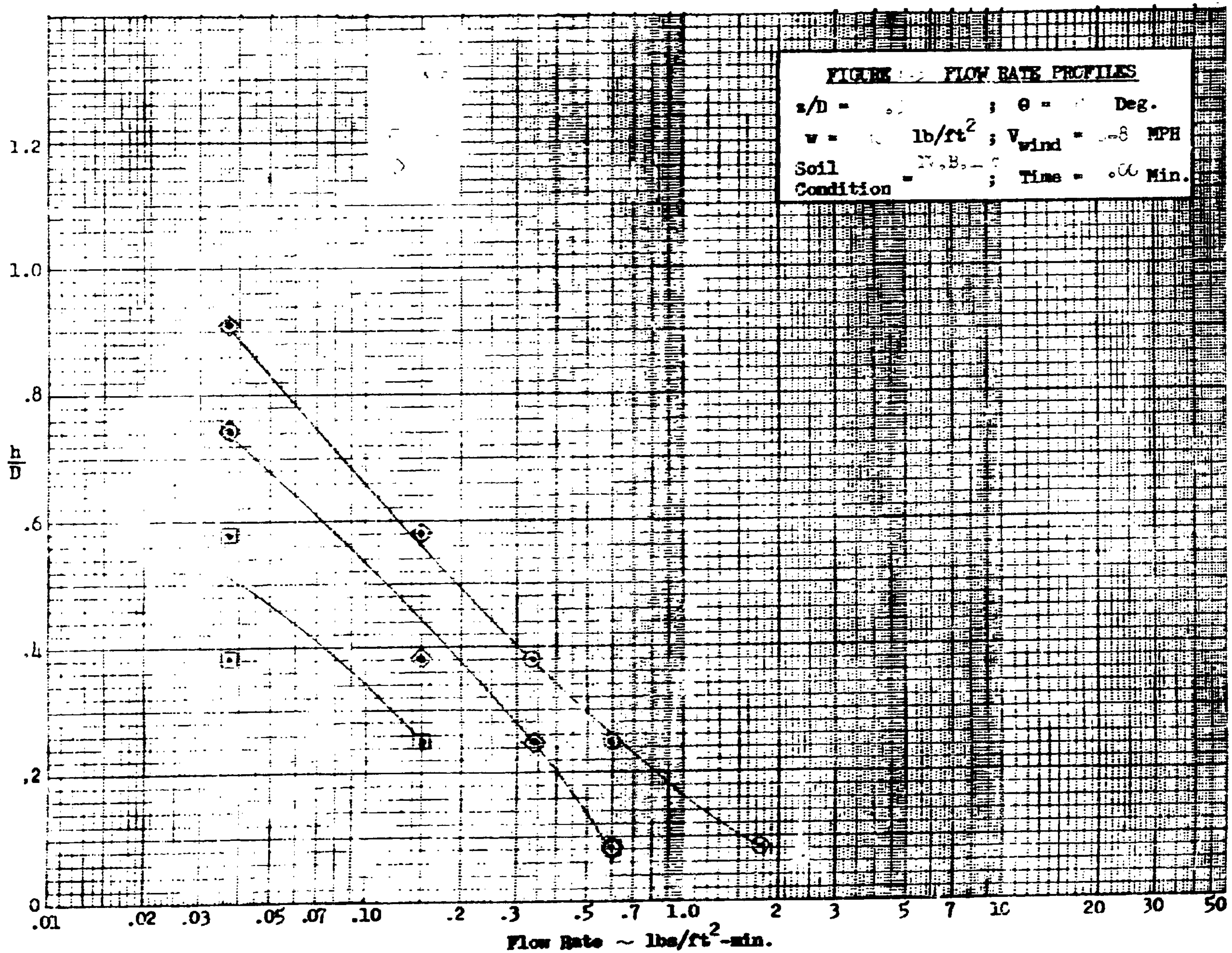


FIGURE FLOW RATE PROFILES
s/D = ; θ = Deg.
w = lb/ft^2 ; V_{wind} = MPH
Soil Condition = ; Time = Min.
$\frac{h}{D}$
0
.2
.4
.6
.8
1.0
1.2
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

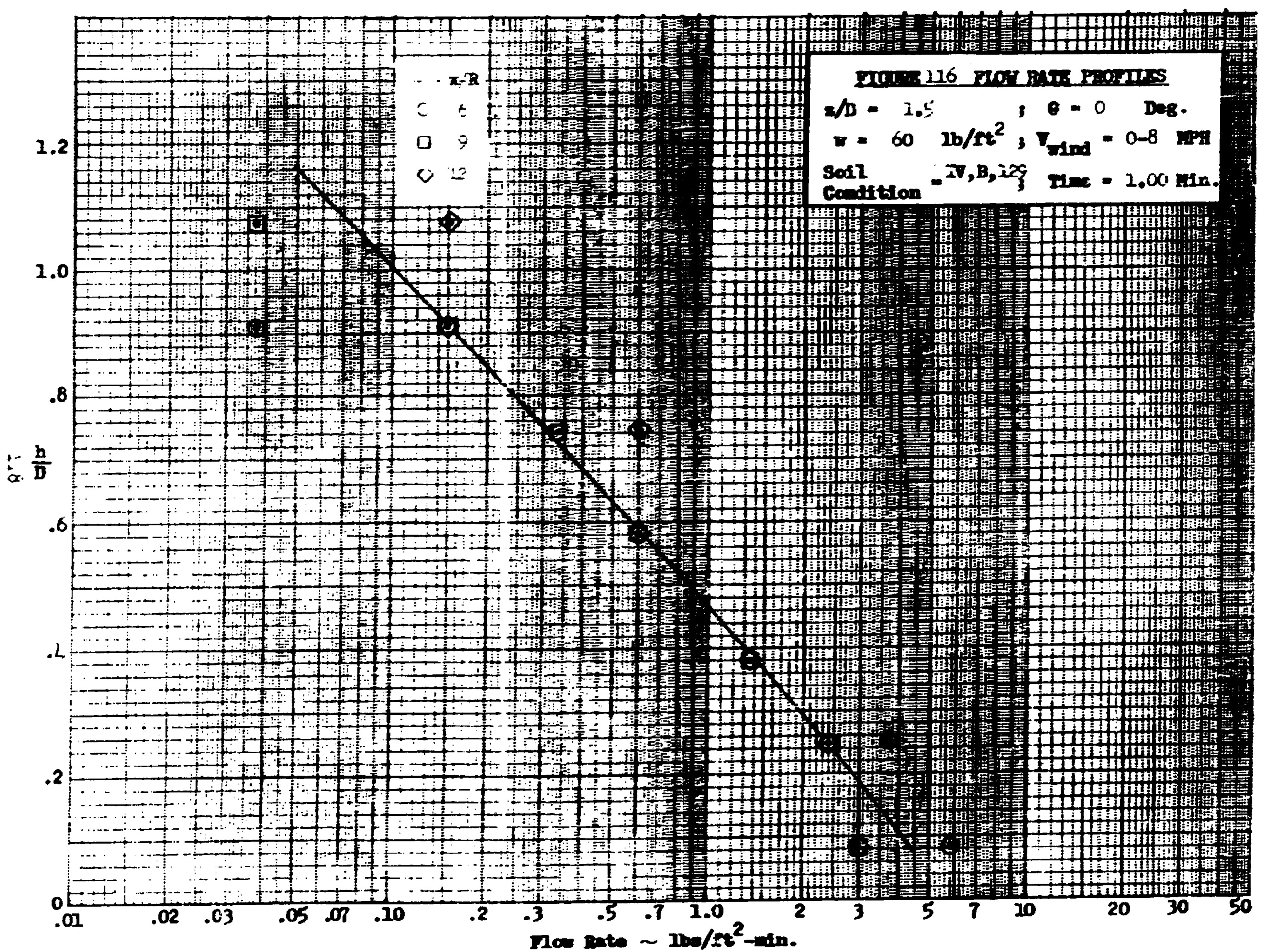


FIGURE 116 FLOW RATE PROFILES
x/D = 1.5 ; θ = 0 Deg.
w = 60 lb/ft² ; V_wind = 0-8 MPH
Soil Condition = IV,B,12 ; Time = 1.00 Min.
x/R
6
9
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.
118

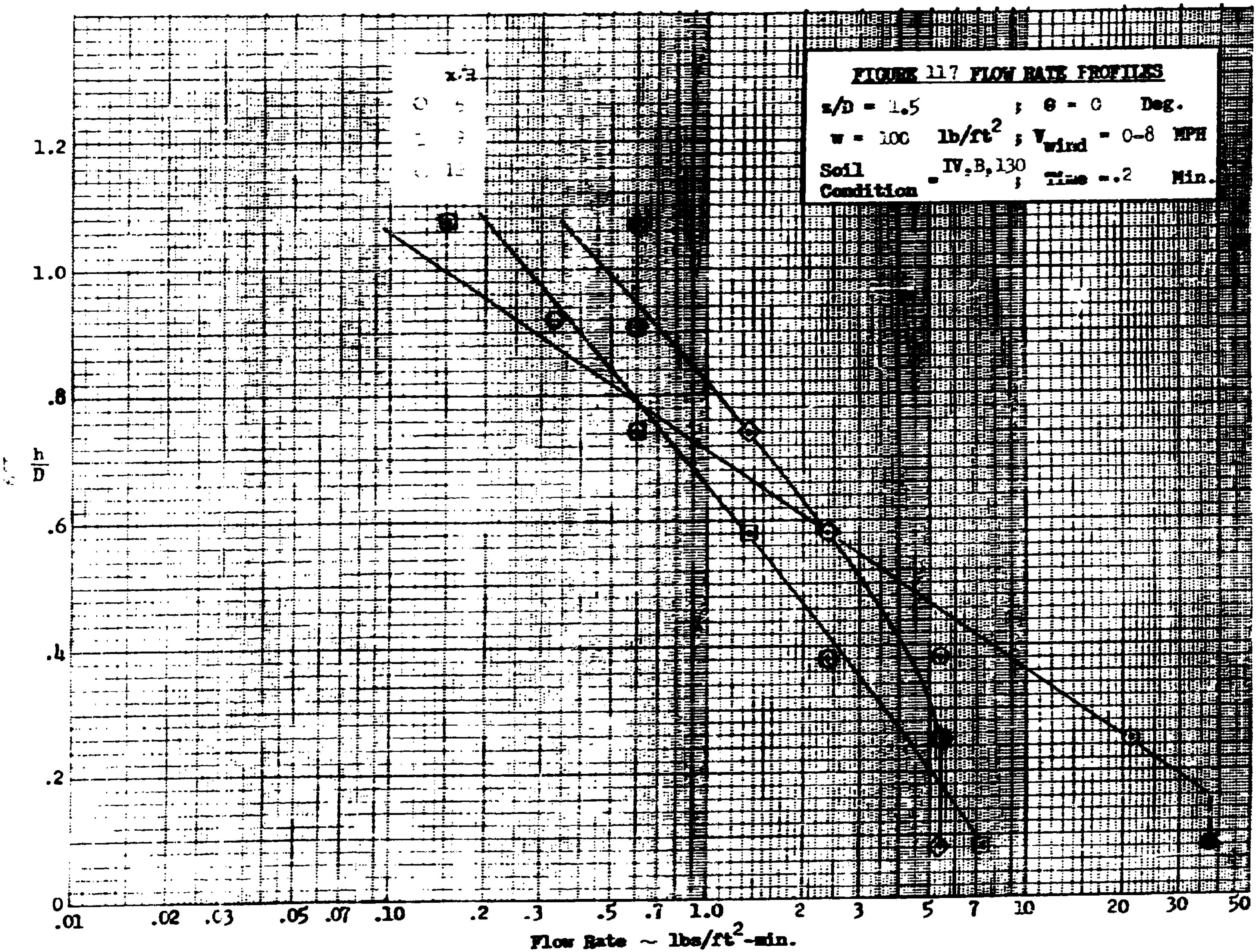


FIGURE 117 FLOW RATE PROFILES
z/D = 1.5 ; θ = 0 Deg.
w = 100 lb/ft² ; V wind = 0-8 MPH
Soil Condition = IV, B, 130 ; Time = .2 Min.
x/D
12
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

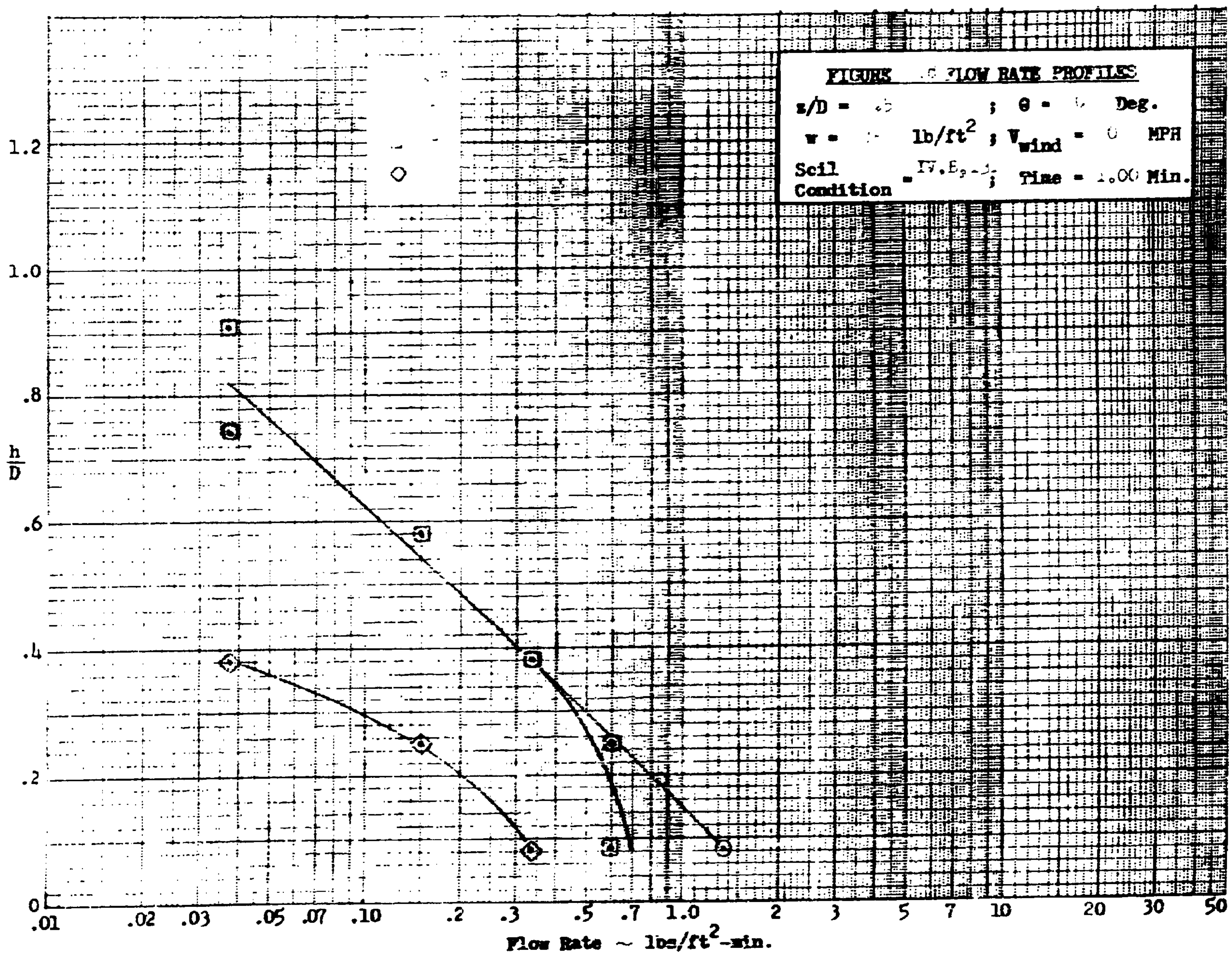


FIGURE FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft^2 ; V_{wind} = MPH
Soil Condition = ; Time = Min.
1.2
1.0
.8
h/D
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

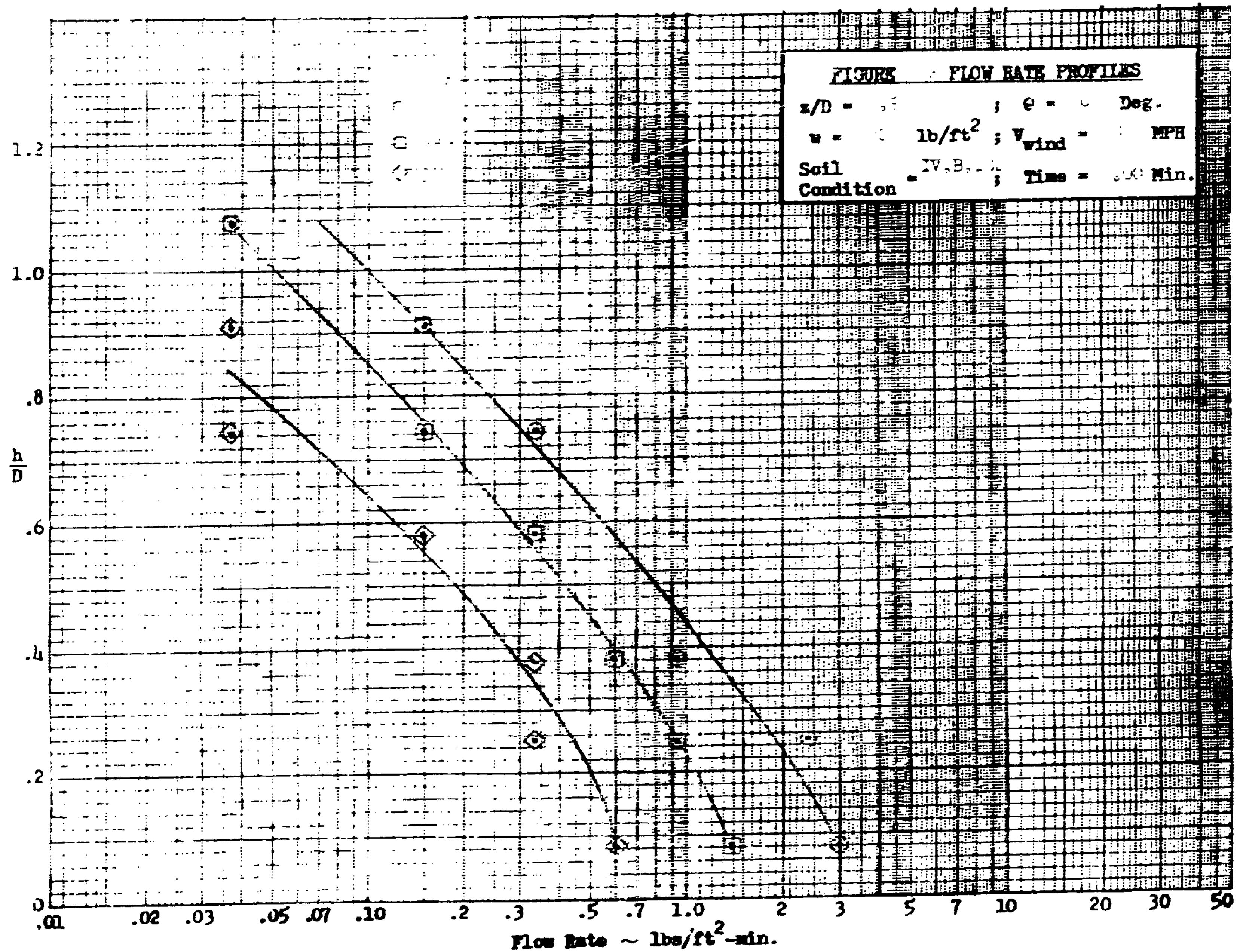


FIGURE FLOW RATE PROFILES
z/D = ; Θ = Deg.
w = lb/ft^2 ; V_{wind} = MPH
Soil Condition = IV.B. ; Time = Min.
1.2
1.0
.8
.6
.4
.2
0
h/D
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft^2-min.

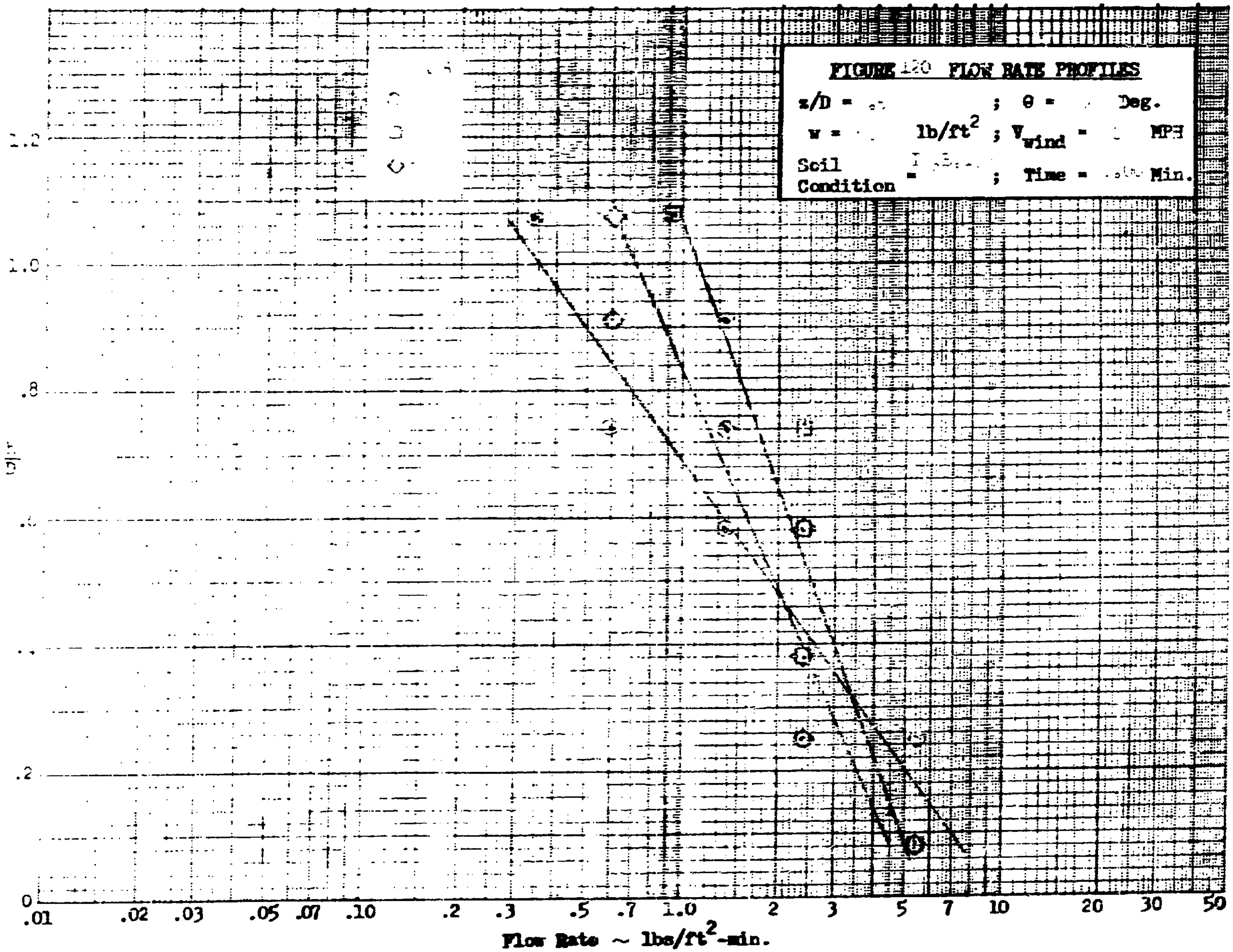


FIGURE 120 FLOW RATE PROFILES
z/D = ; θ = Deg.
w = lb/ft²; V_wind = MPH
Soil Condition = ; Time = Min.
1.2
1.0
.8
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

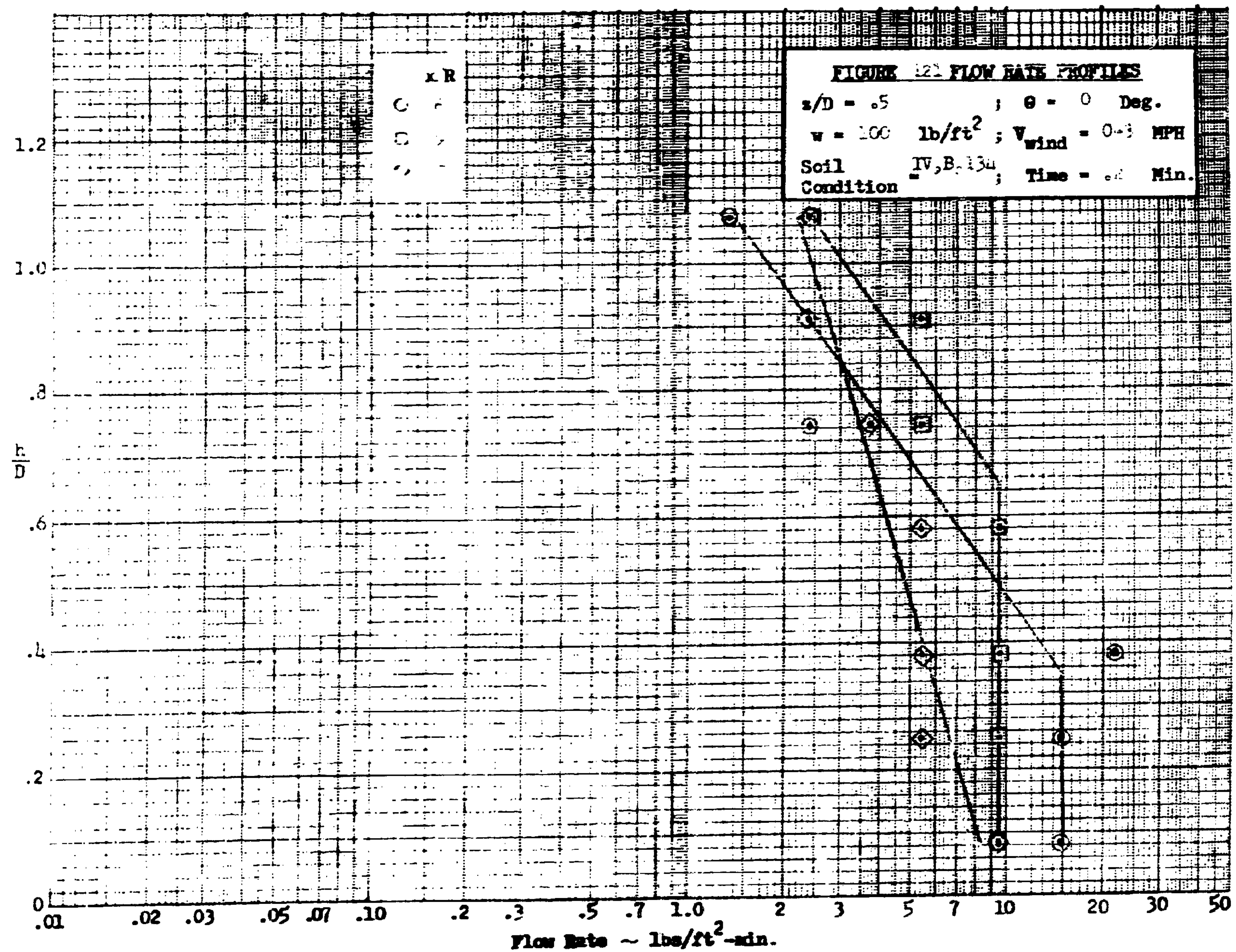


FIGURE 121 FLOW RATE PROFILES
z/D = .5 ; θ = 0 Deg.
w = 100 lb/ft² ; V_wind = 0-3 MPH
Soil Condition = IV, B, 13a ; Time = Min.
x R
h/D
1.2
1.0
.8
.6
.4
.2
0
.01
.02
.03
.05
.07
.10
.2
.3
.5
.7
1.0
2
3
5
7
10
20
30
50
Flow Rate ~ lbs/ft²-min.

FIGURE 122 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 30, θ = 0

IV-B135

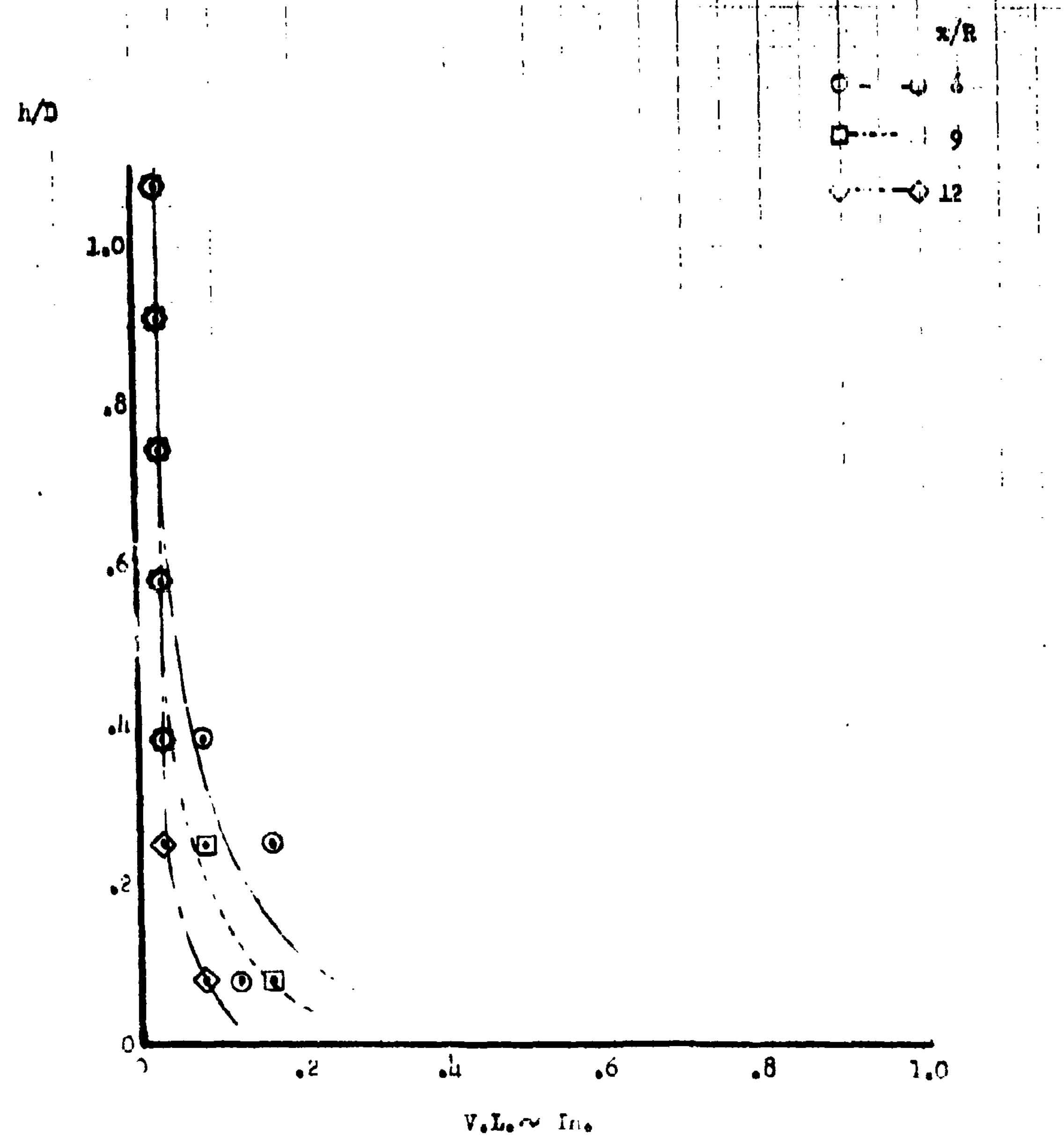


FIGURE 123 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 3, w = 60, θ = 0

IV-B136

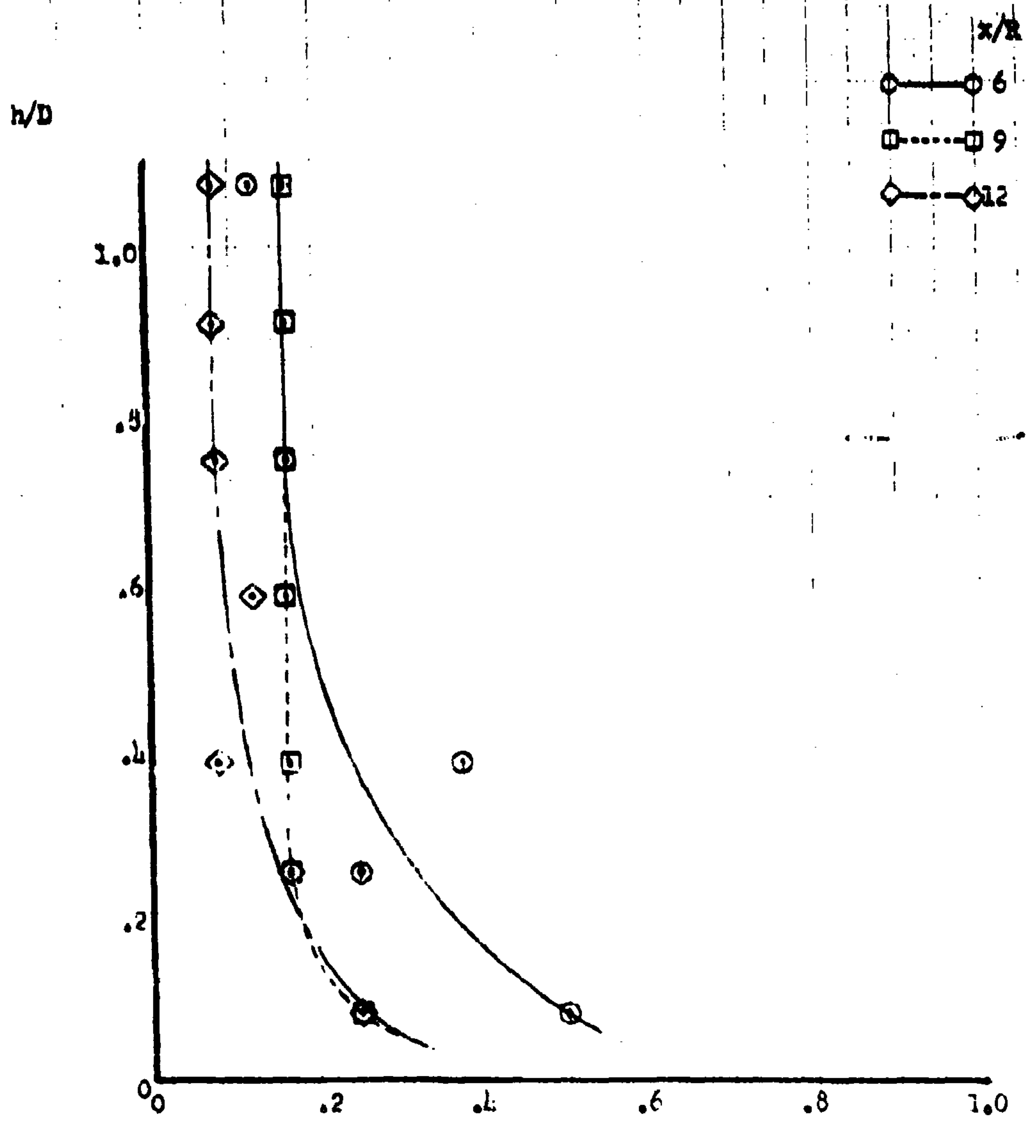


FIGURE 124 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

$Z/D = 3,\ w = 100,\ \theta = 0$

IV-B137

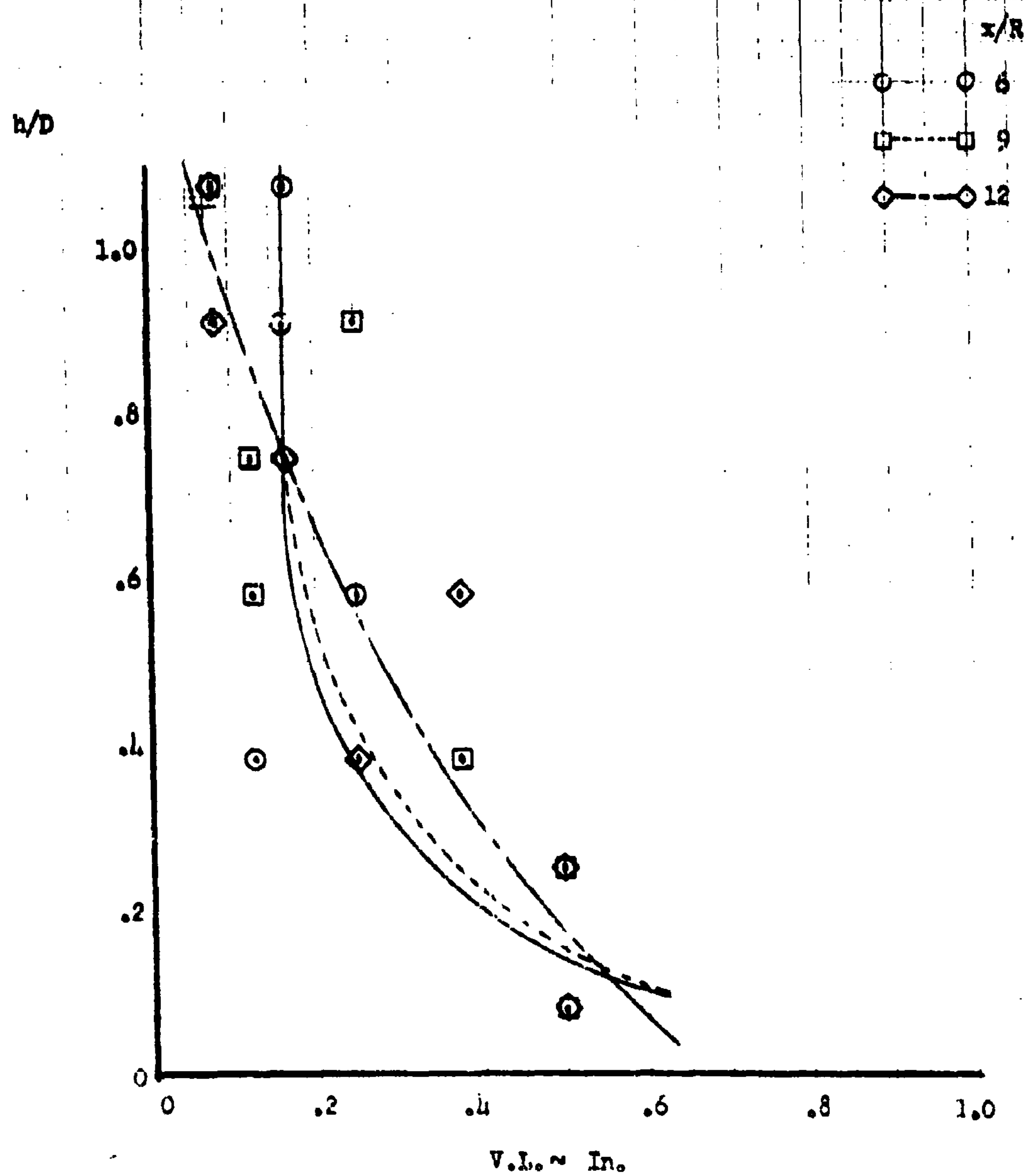
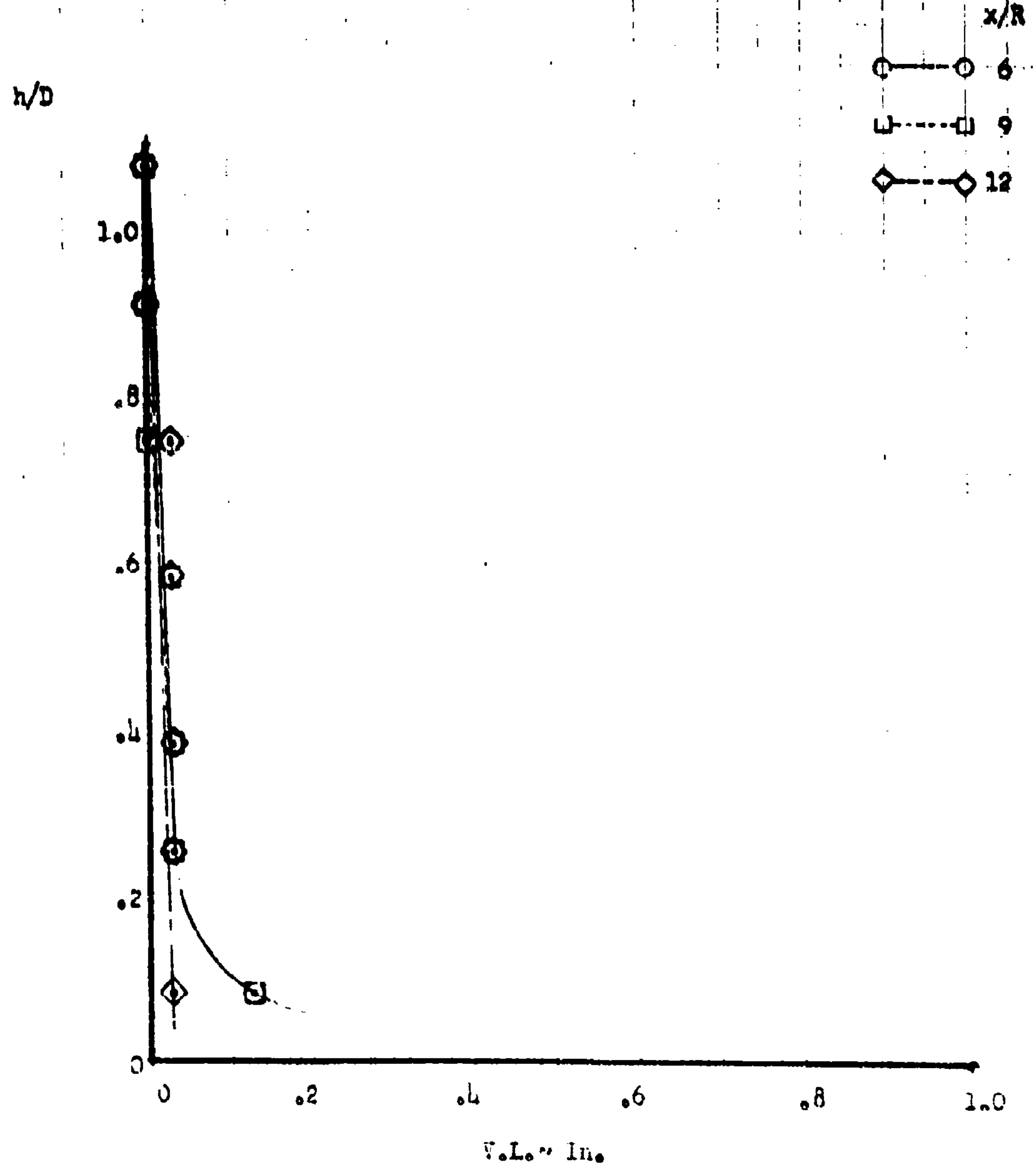


FIGURE 125 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

$Z/D = 1.5$, $w = 15$, $\theta = 0$

IV-B127



#-12D

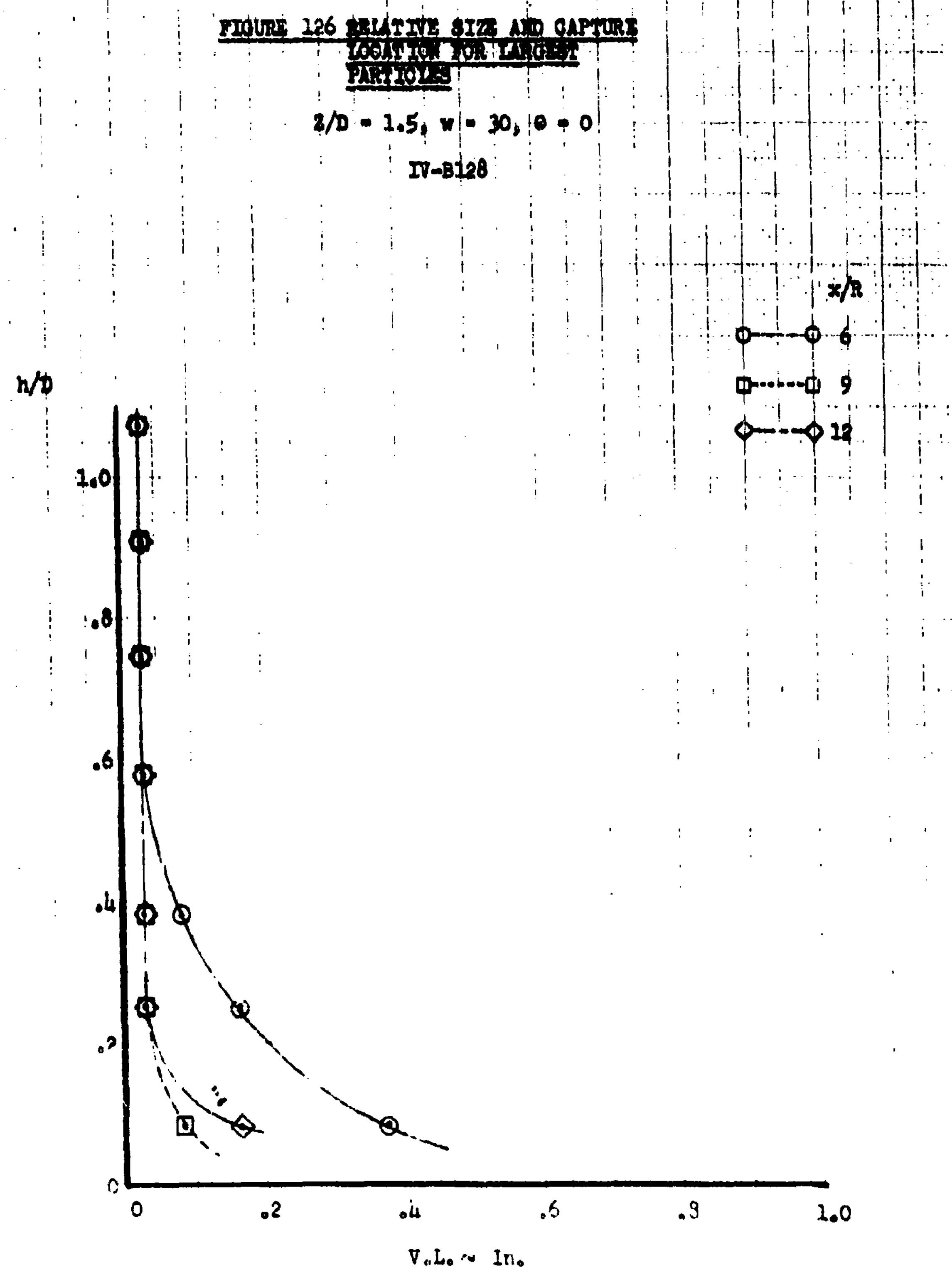


FIGURE 126 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES
Z/D = 1.5, w = 30, Θ = 0
IV-B128
x/R
6
9
12
h/D
1.0
.8
.6
.4
.2
0
0
.2
.4
.6
.8
1.0
V.L. ~ In.

FIGURE 127 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = 60, θ = 0

IV-B129

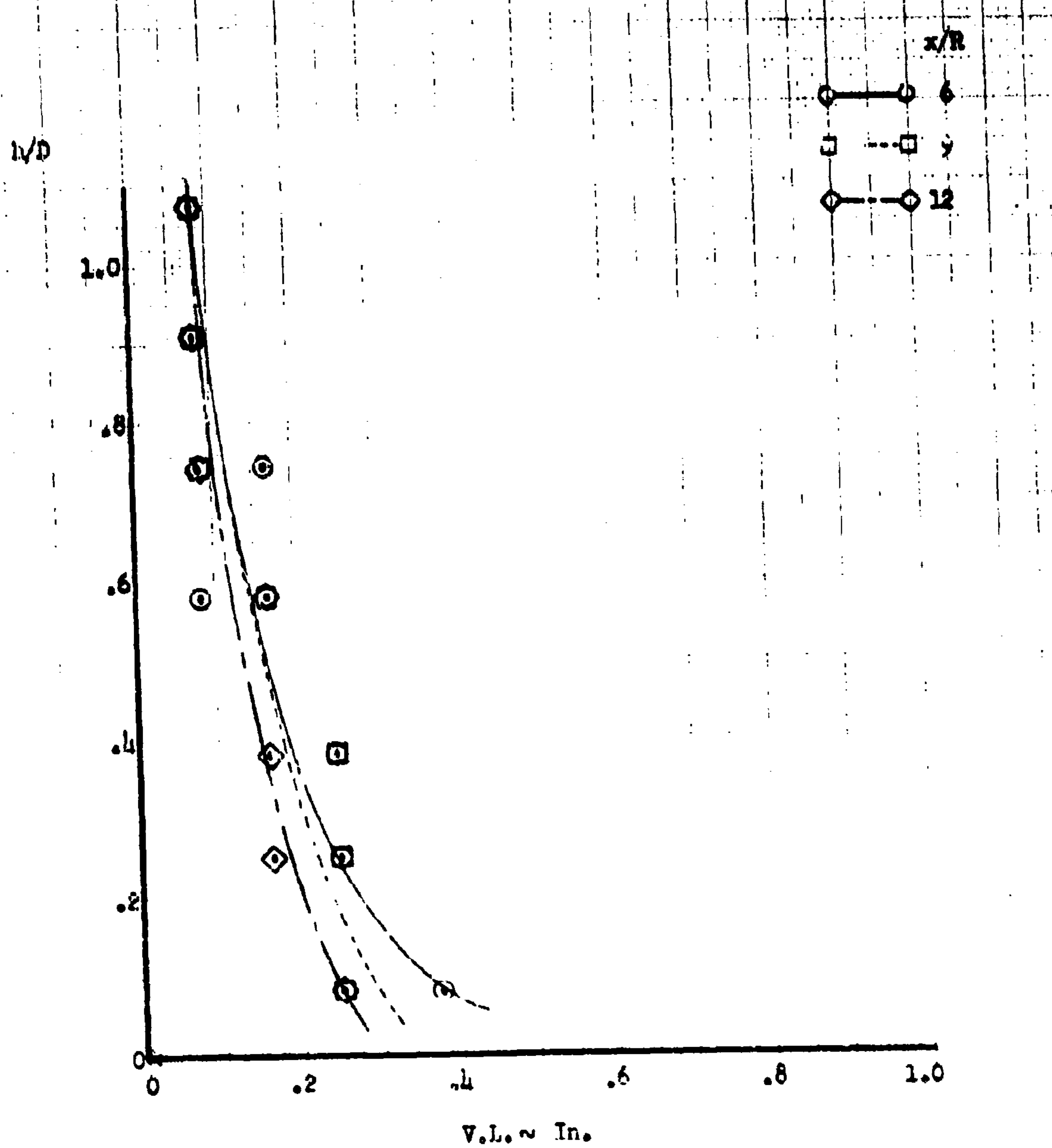


FIGURE 128 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = 1.5, w = 100, θ = 0

IV-B130

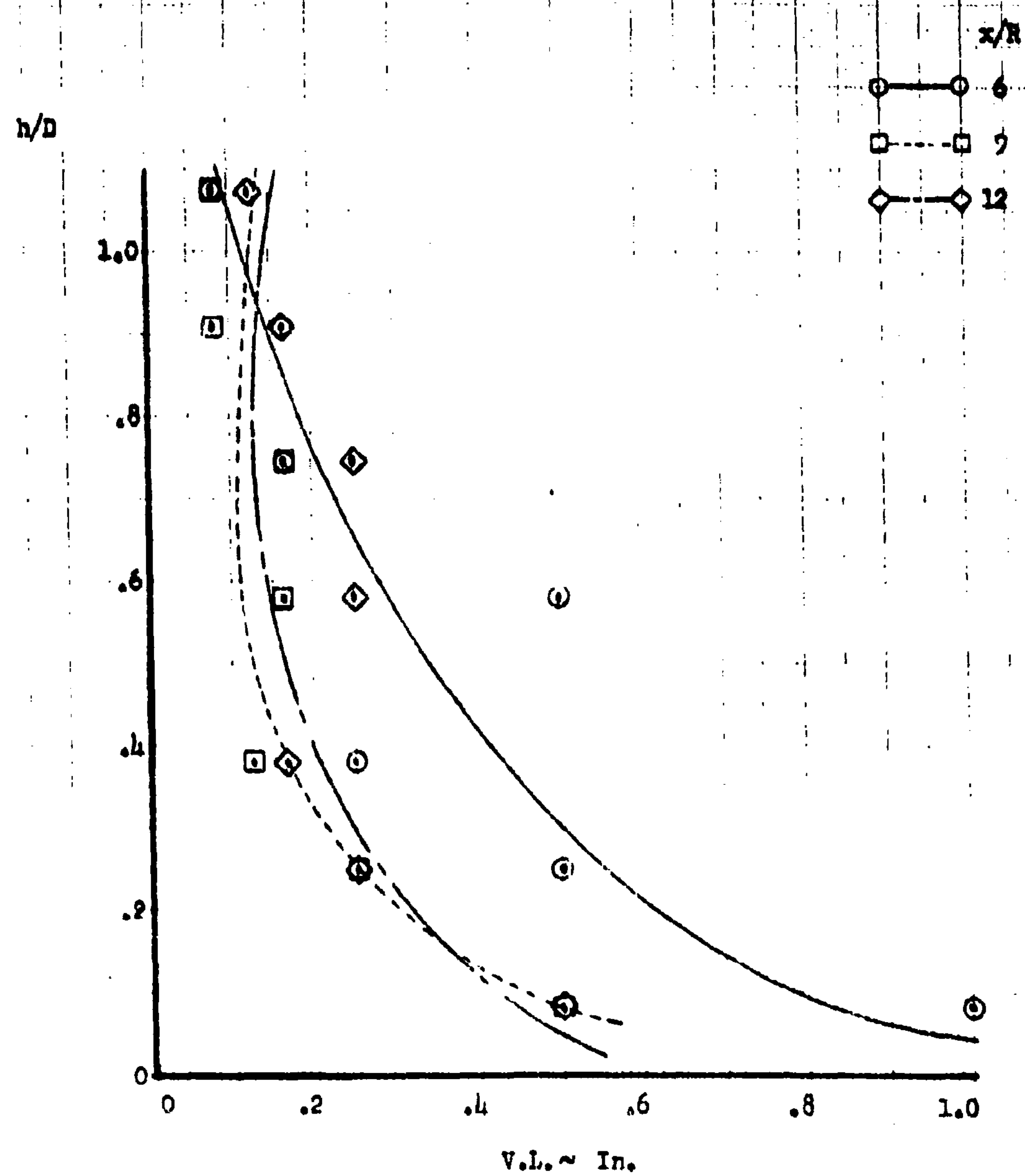


FIGURE 129 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

$\ell/D = .5, w = 15, \theta = 0$

IV-B131

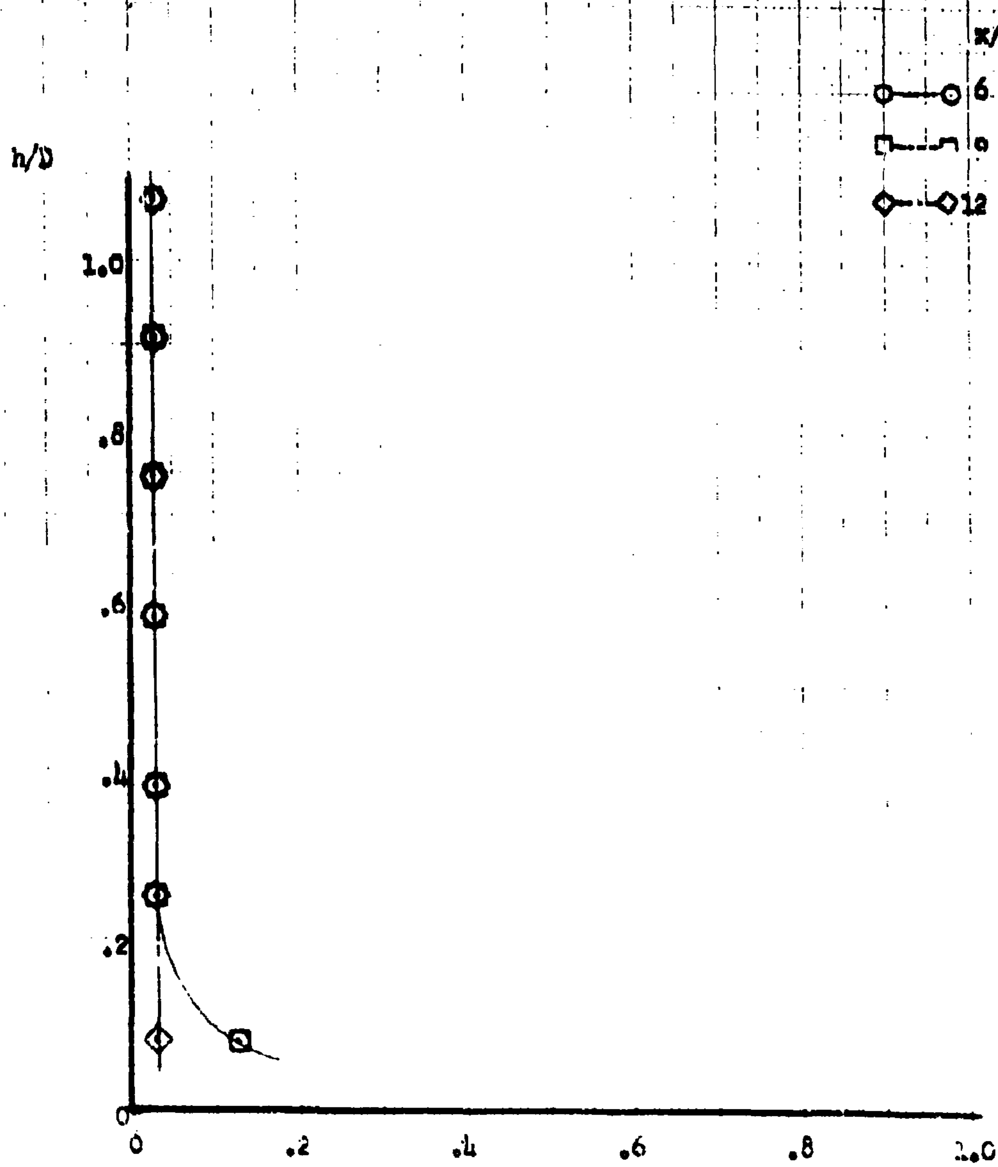


FIGURE 130 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = .5, v = 30, θ = 0

IV-B132

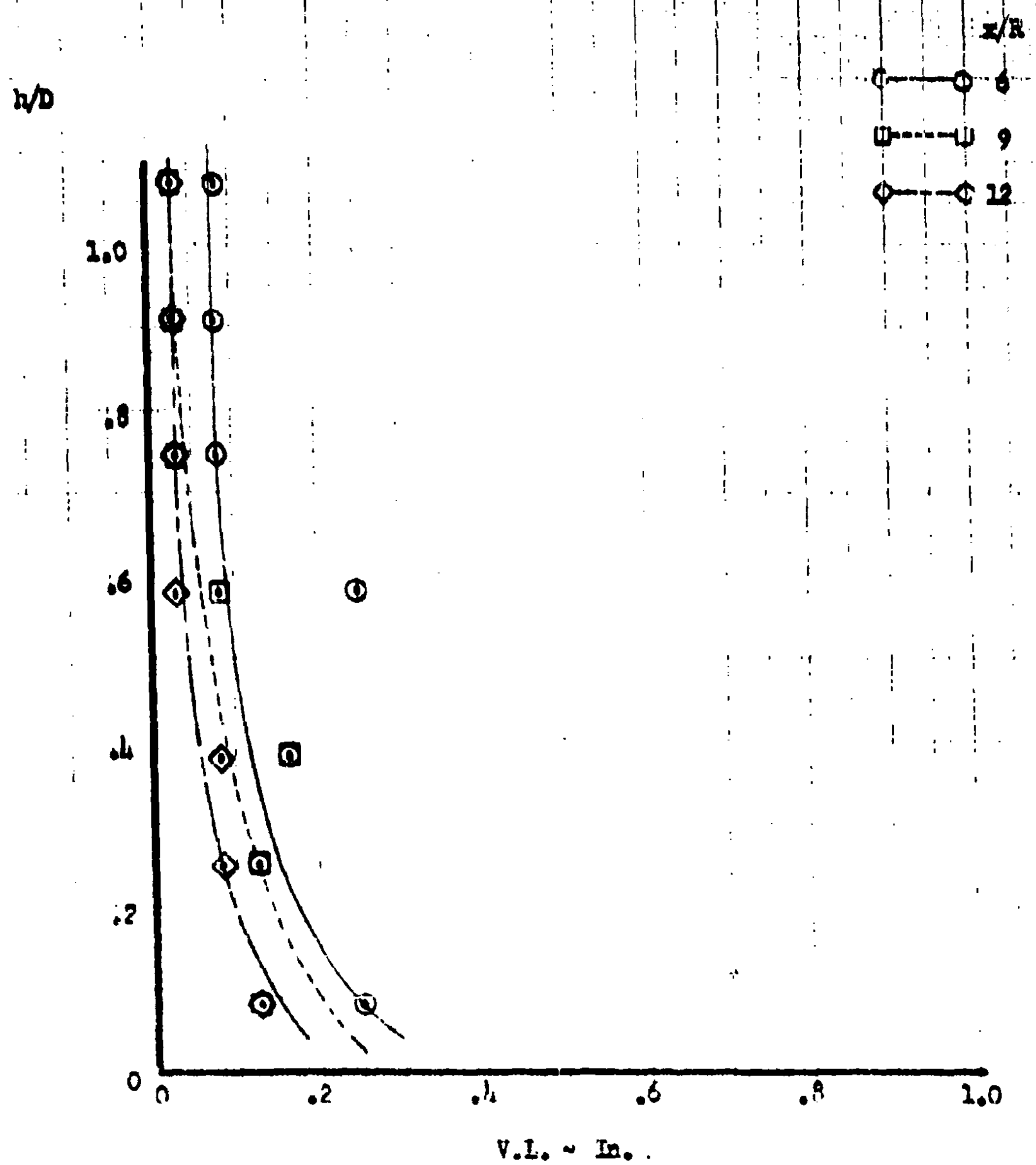


FIGURE 133 RELATIVE SIZE AND CAPTURE LOCATION FOR LARGEST PARTICLES

Z/D = .5, w = 60, θ = 0

IV-B133

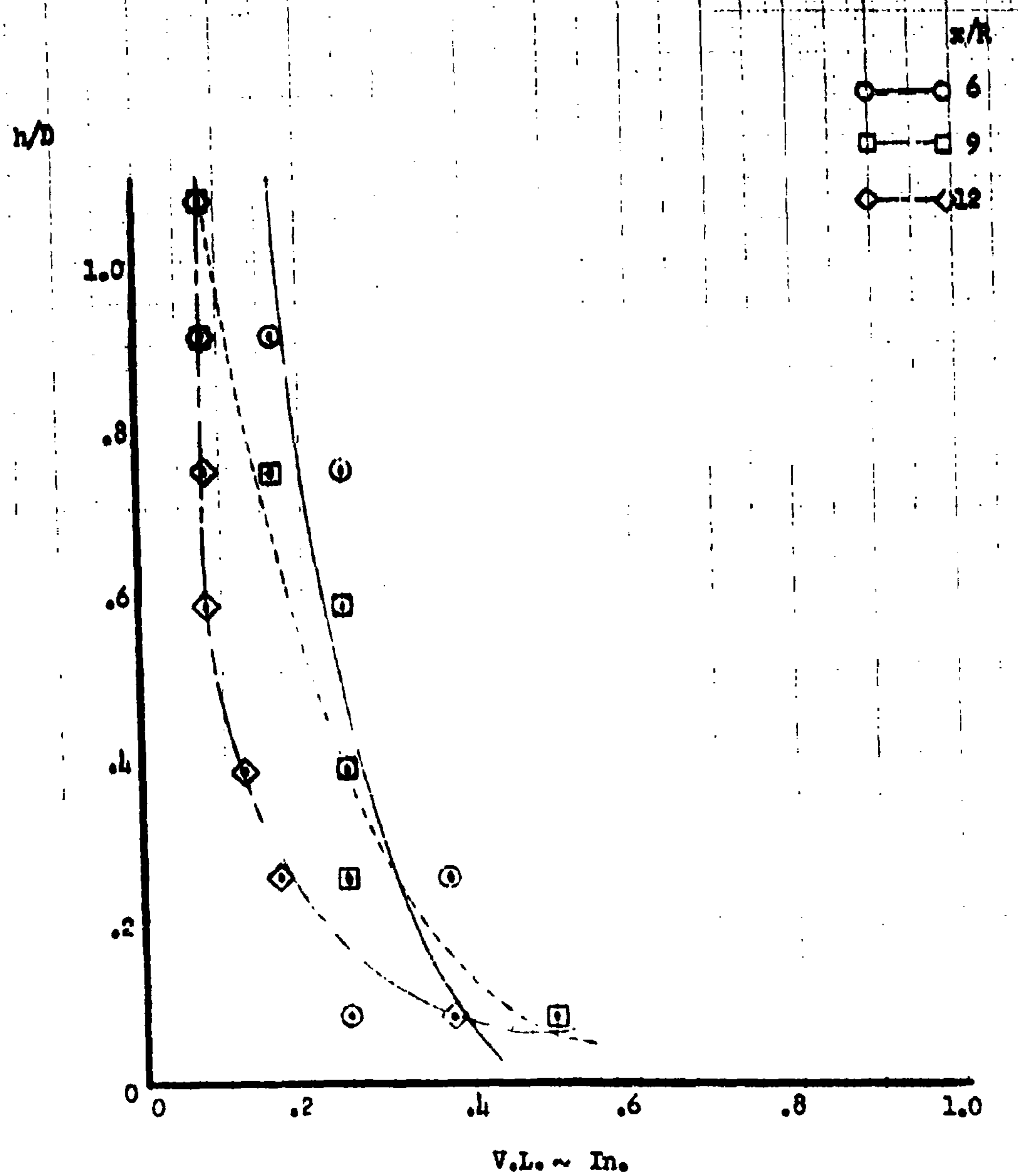


FIGURE 132 RELATIVE SIZE AND CAPTURE LOCATION FOR LONGER PARTICLES

Z/D = .5, v = 100, θ = 0

IV-B134

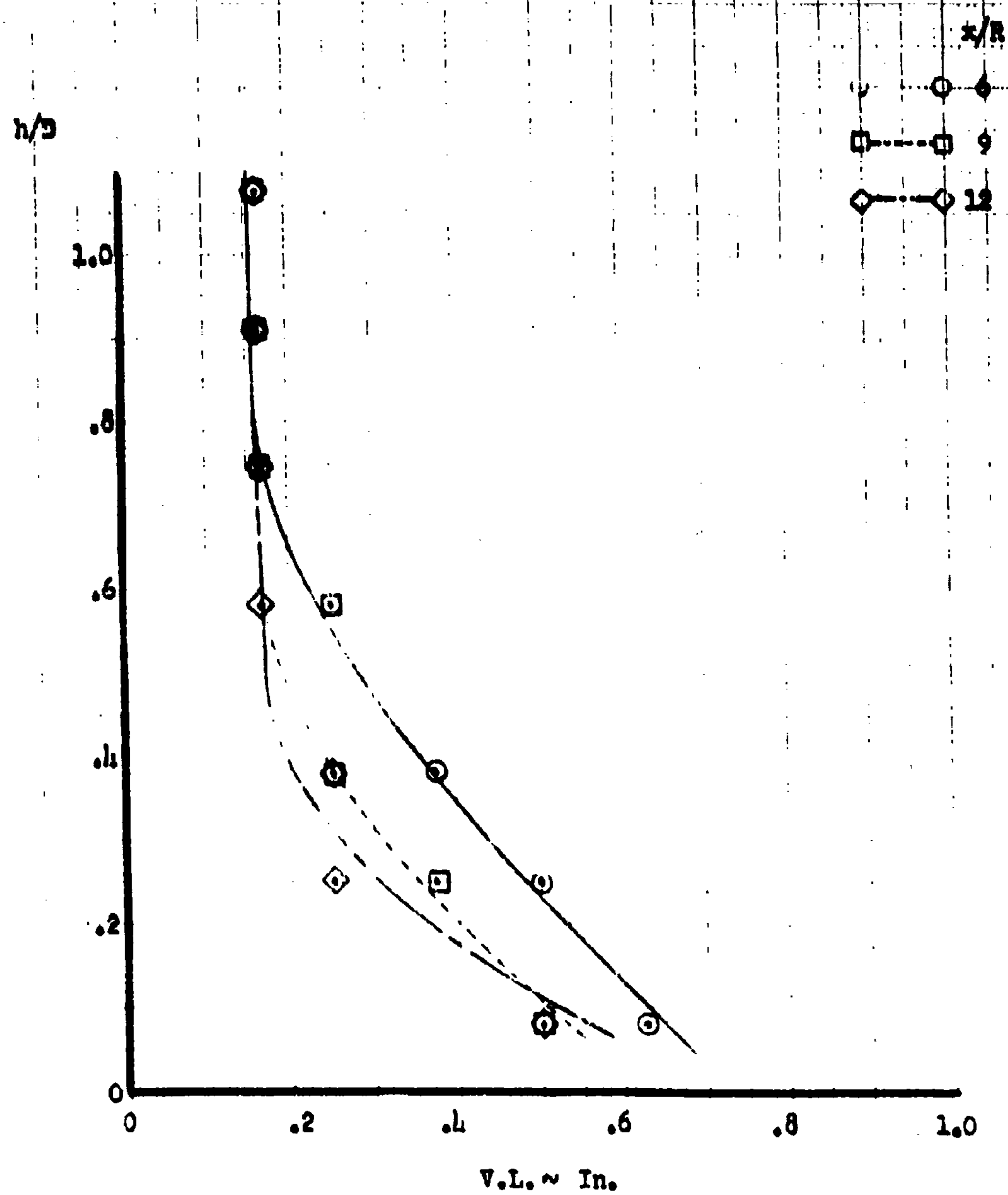


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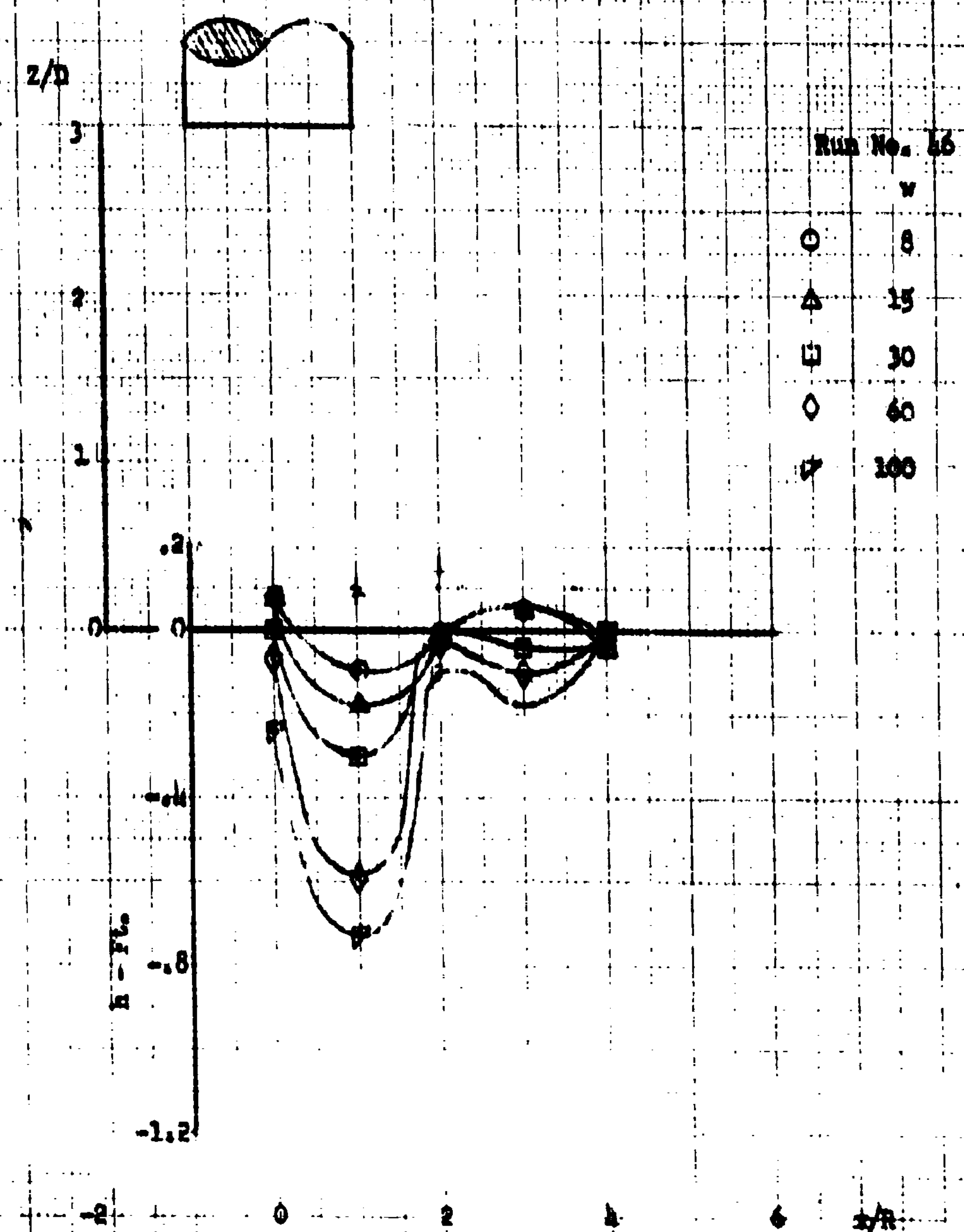
FIGURE 133 SURFACE DEFLECTION

V-A16



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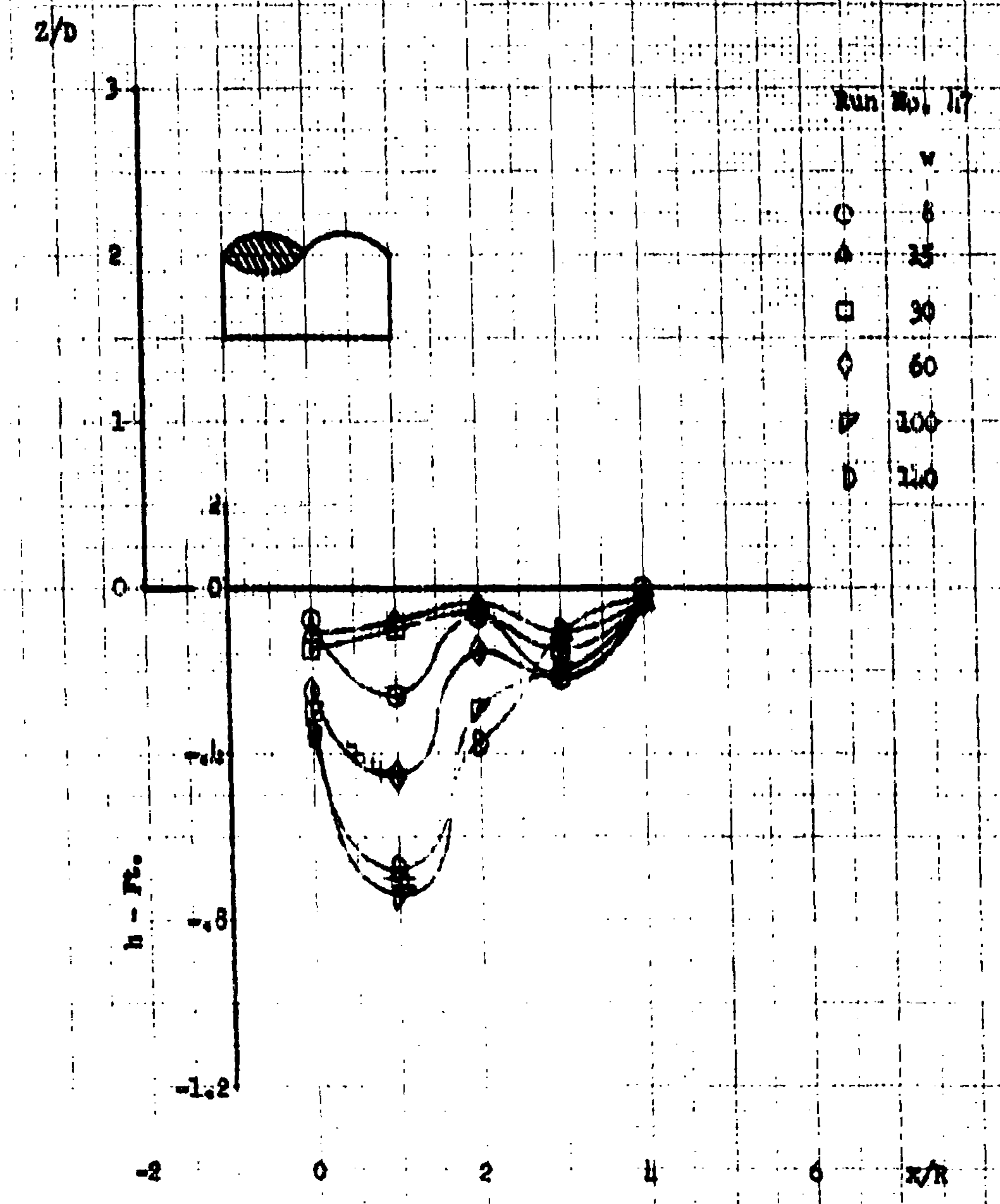
CHECKED			TITLE:	MODEL
APPROVED				REPORT NO.

FIGURE 134 SURFACE DEFLECTION

V-A47



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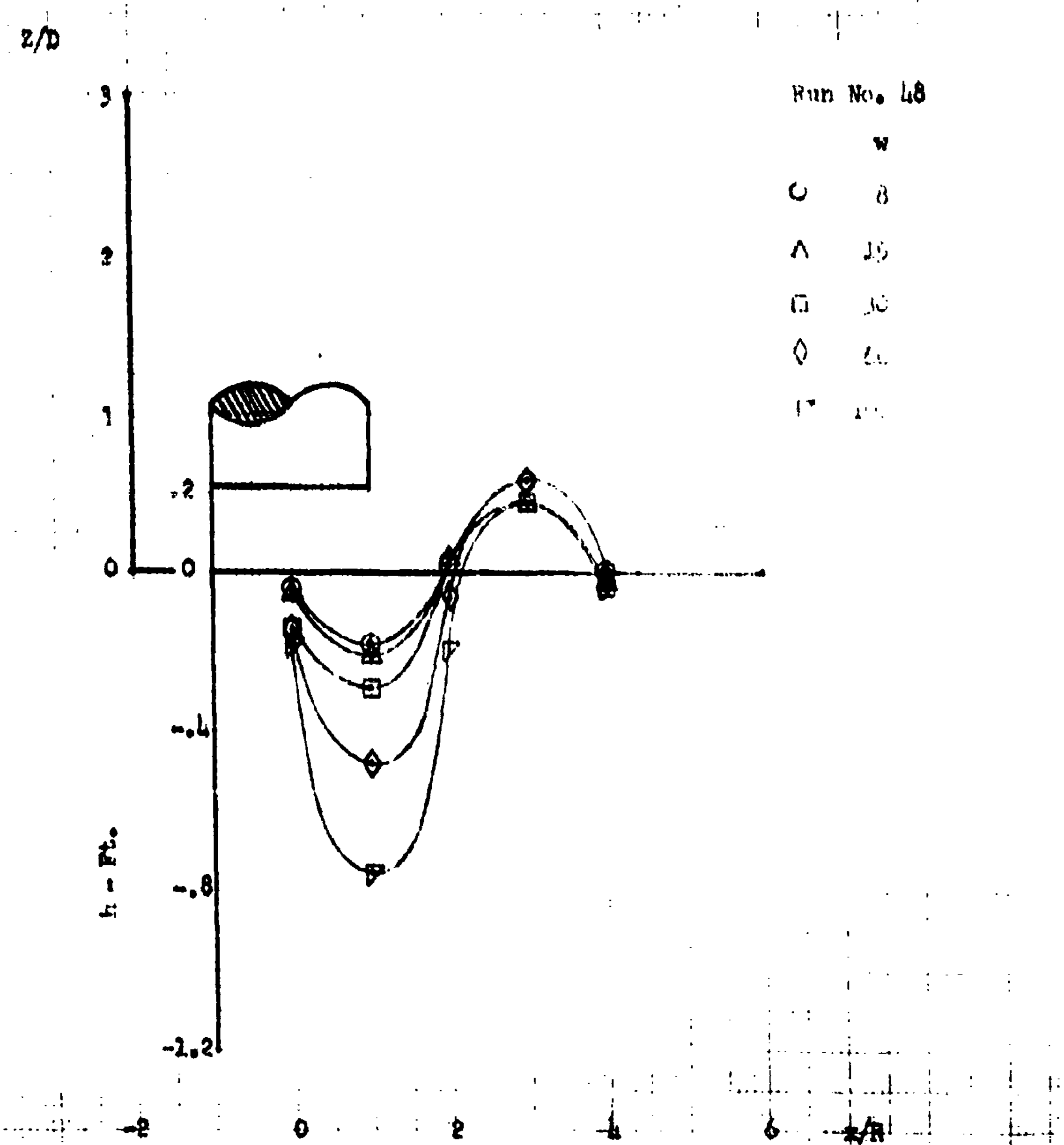
APPROVED				REPORT NO.

FIGURE 135 SURFACE DEFLECTION

V-A48



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APPROVED				REPORT NO.

FIGURE 136 SURFACE DEFLECTION

V-450

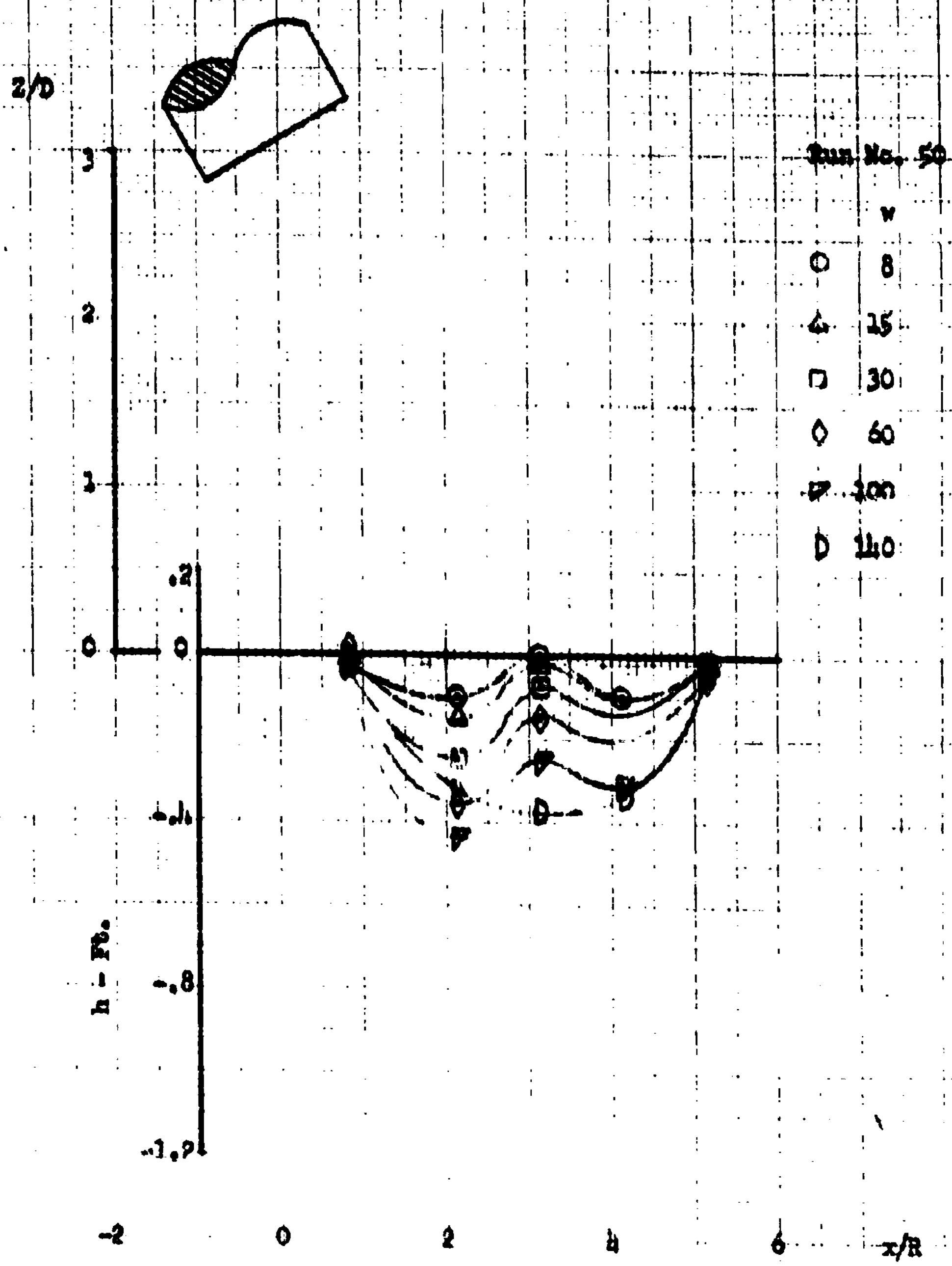

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FIGURE 137 SURFACE DEFLECTION

V-A49

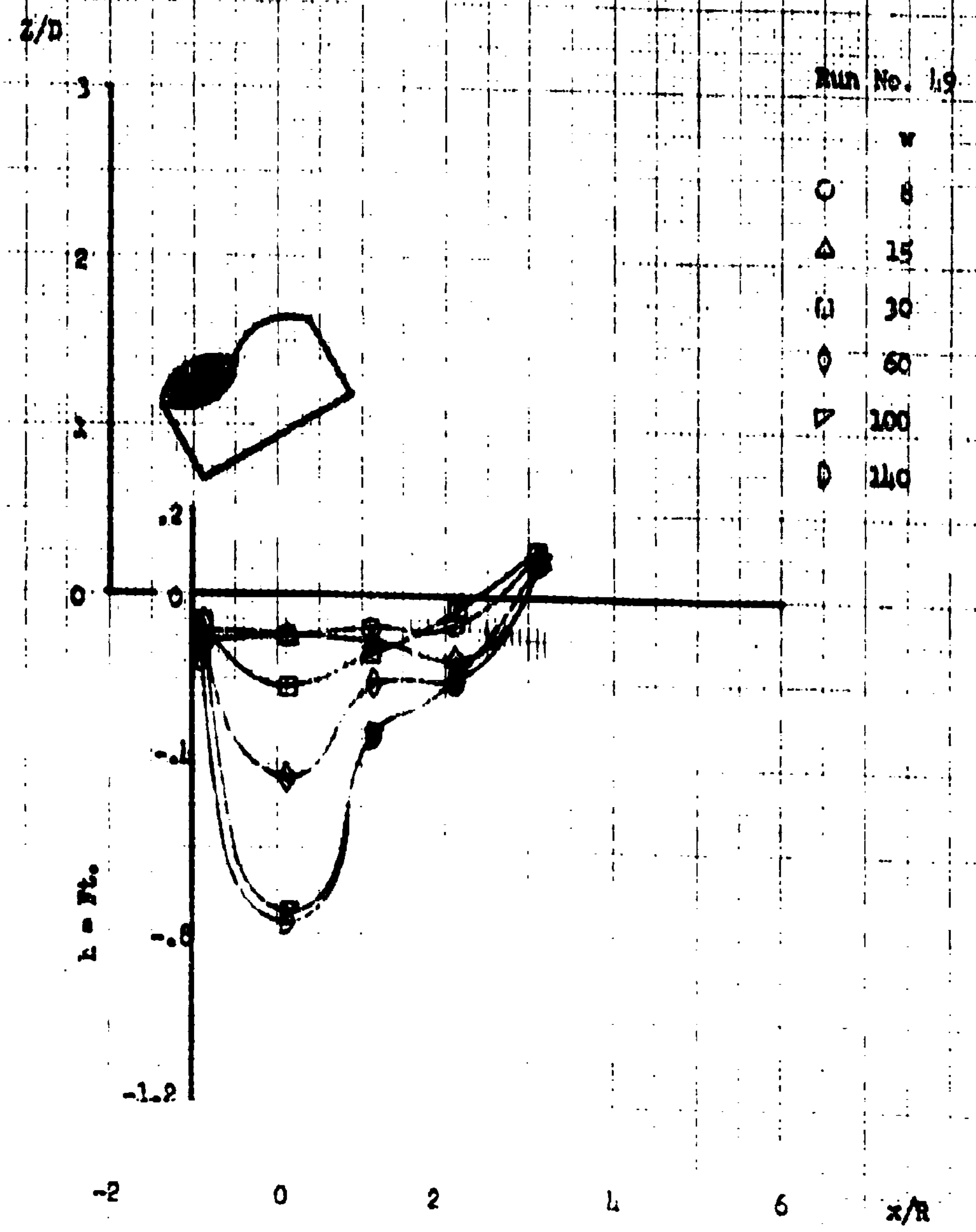
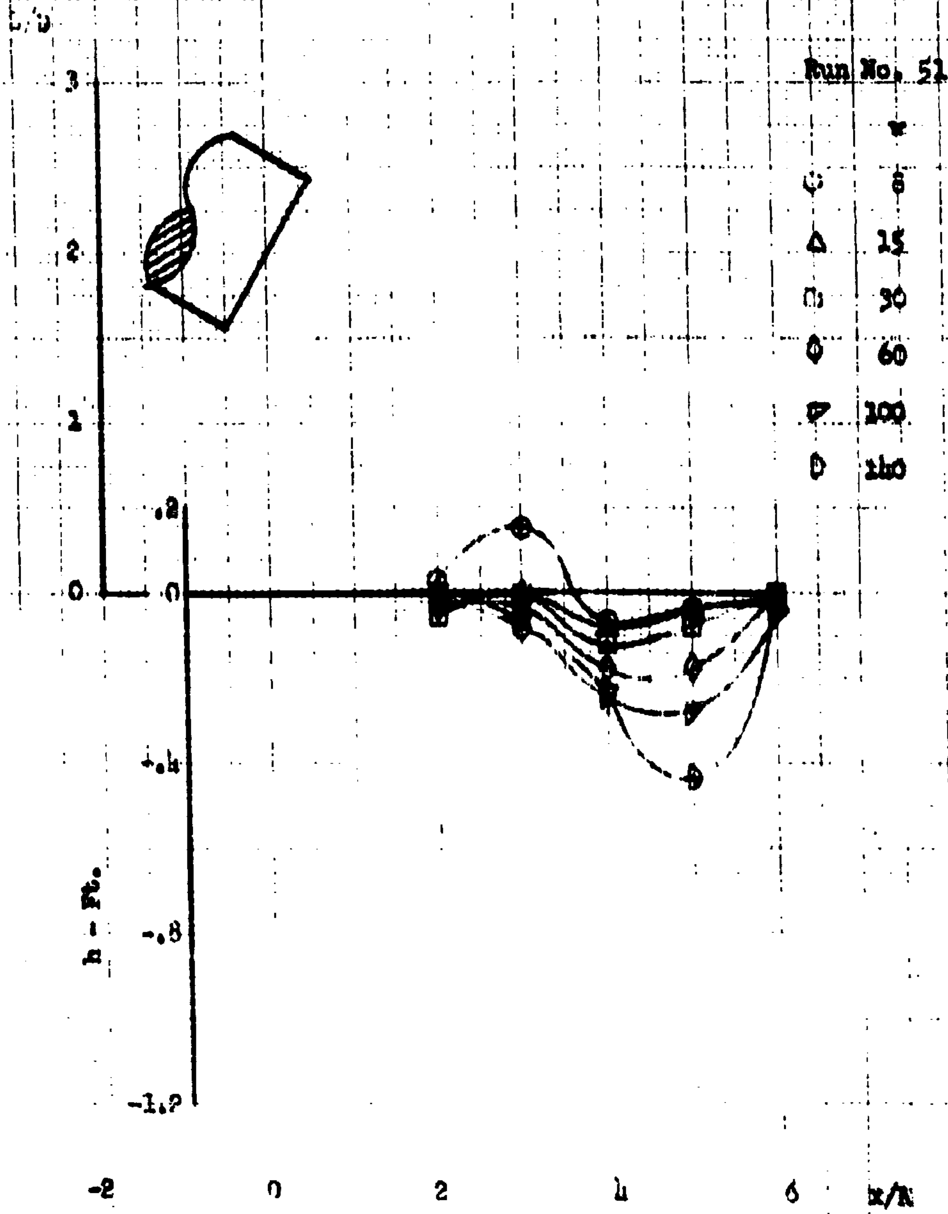


FIGURE 138 SURFACE DEFLECTION

V-A51



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APPROVED				REPORT NO.

FIGURE 139 WAVE AMPLITUDE

V=46

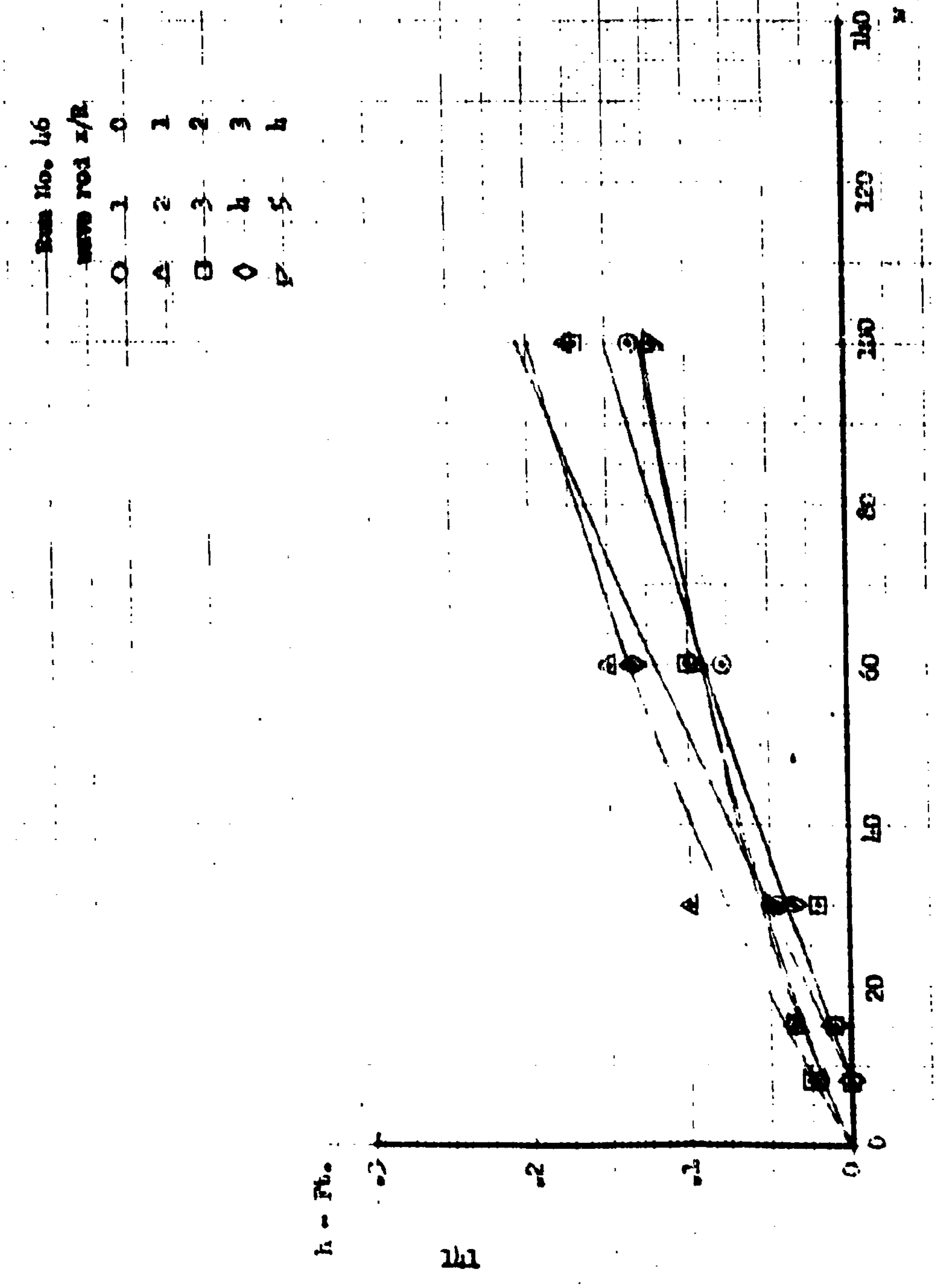

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FIGURE 140 WAVE AMPLITUDE

V-447

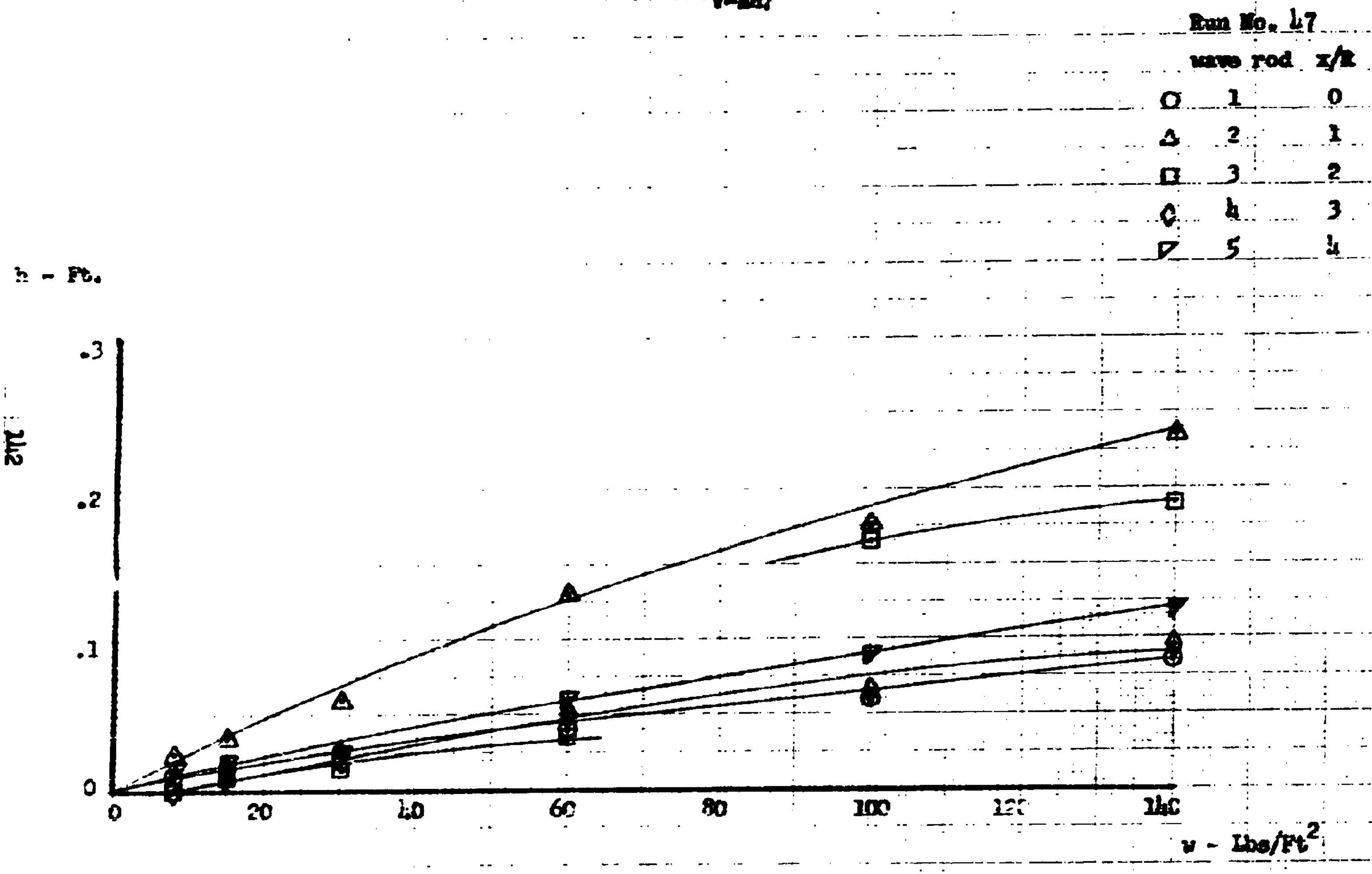

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FIGURE 141 WAVE AMPLITUDE

V-148

Run No. 48

	wave rod	x/R
○	1	0
△	2	1
□	3	2
◇	4	3
▽	5	4

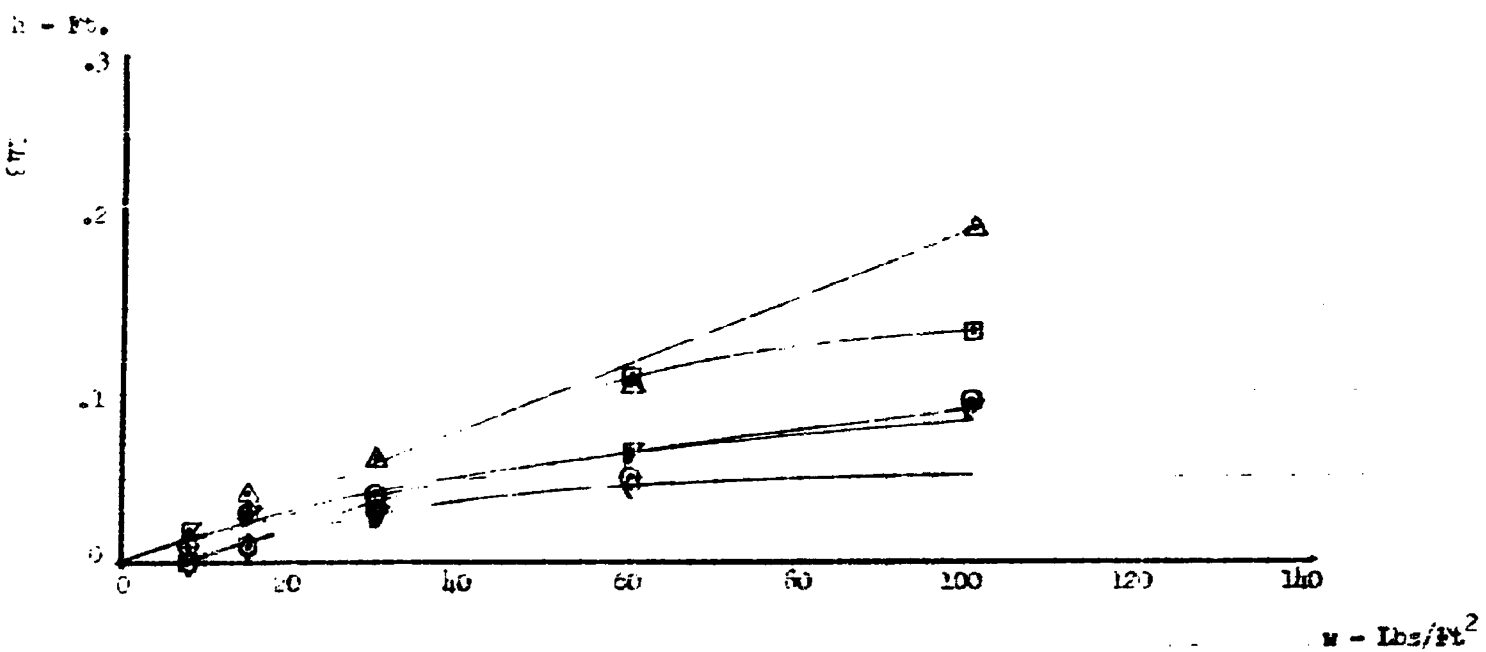

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FIGURE 142 WAVE AMPLITUDE

V-150

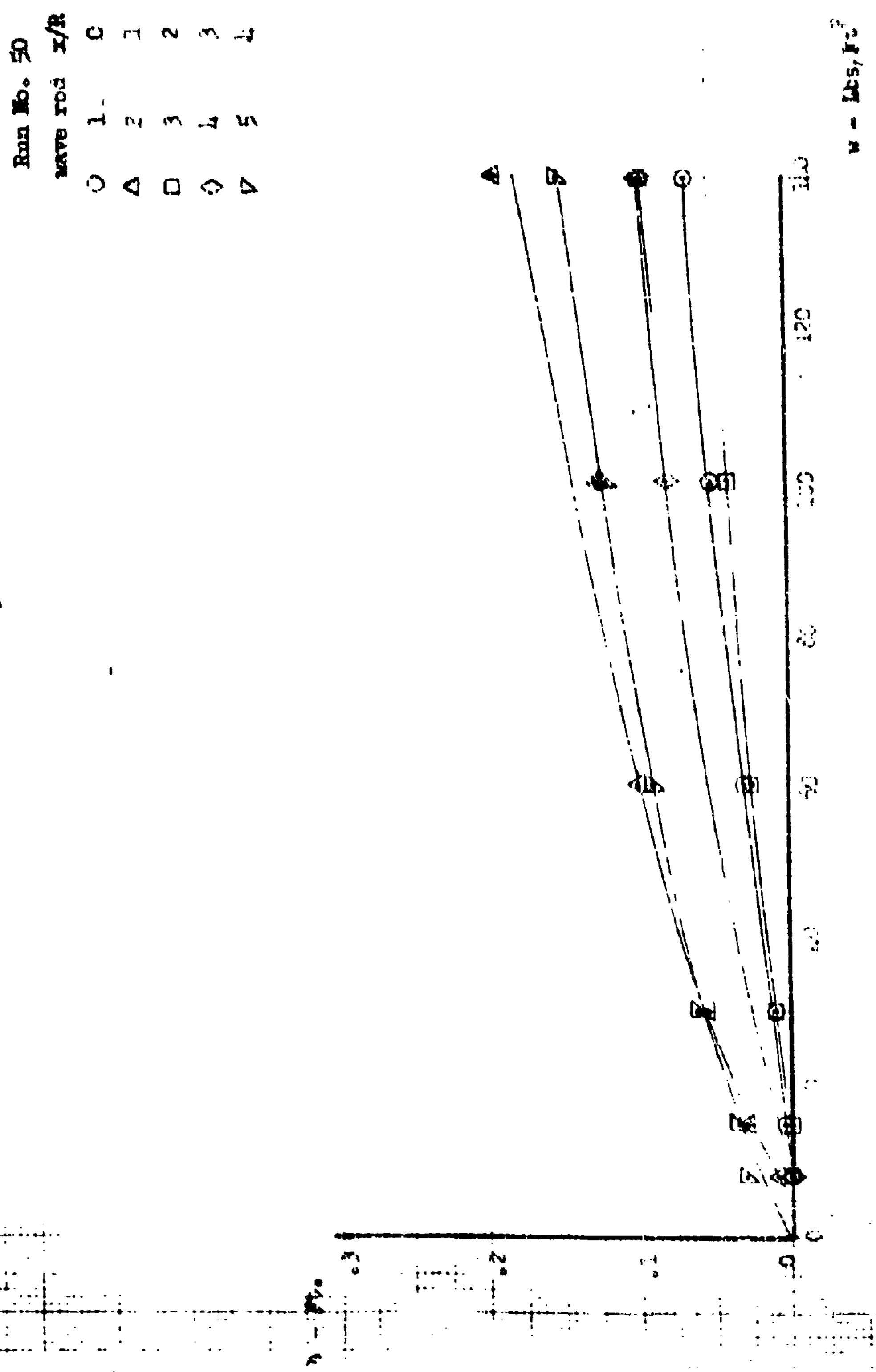

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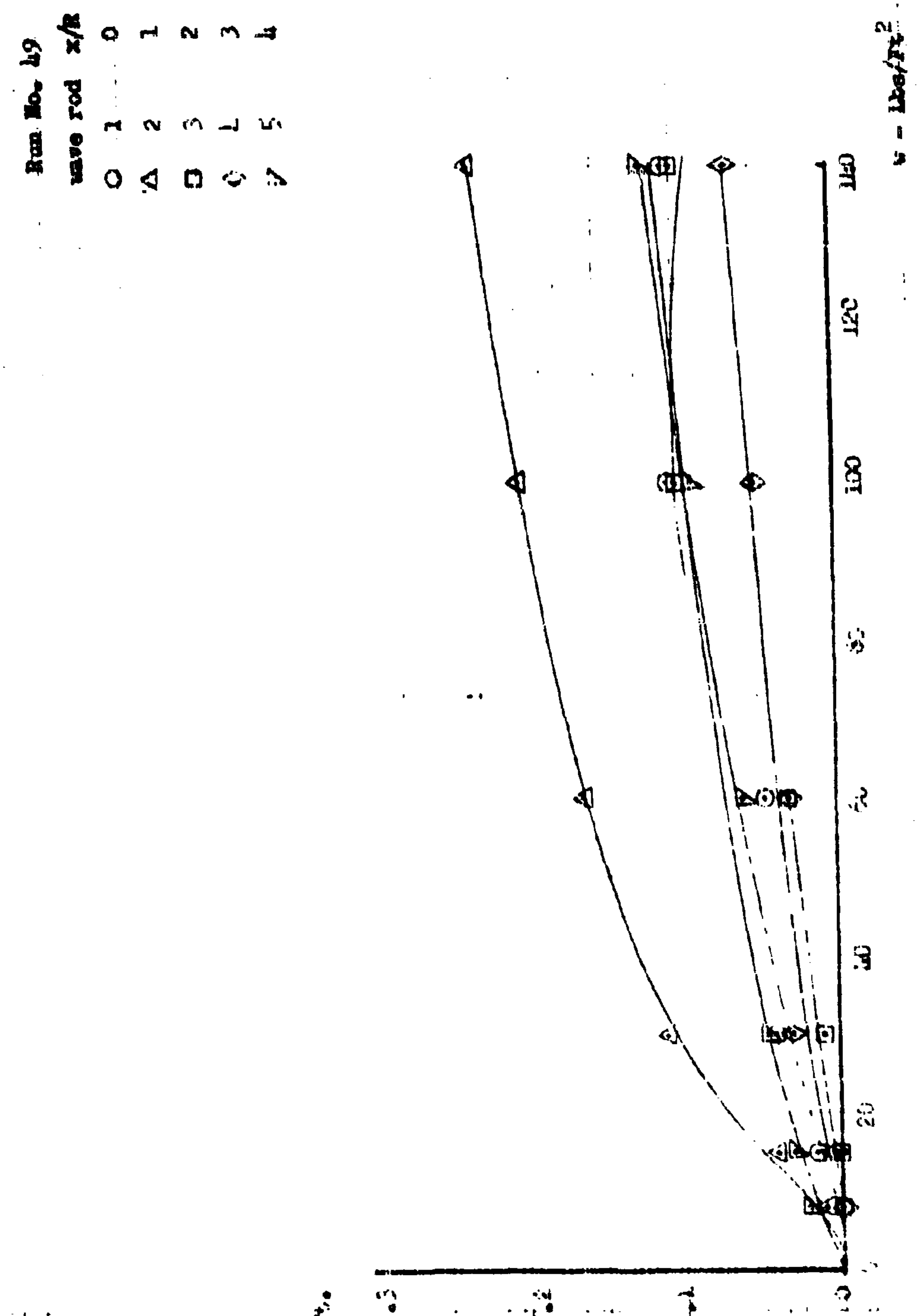
FIGURE 143 WAVE AMPLITUDE

V-49



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APPROVED				REPORT NO.

FIGURE 14 WAVE AMPLITUDE

V-451

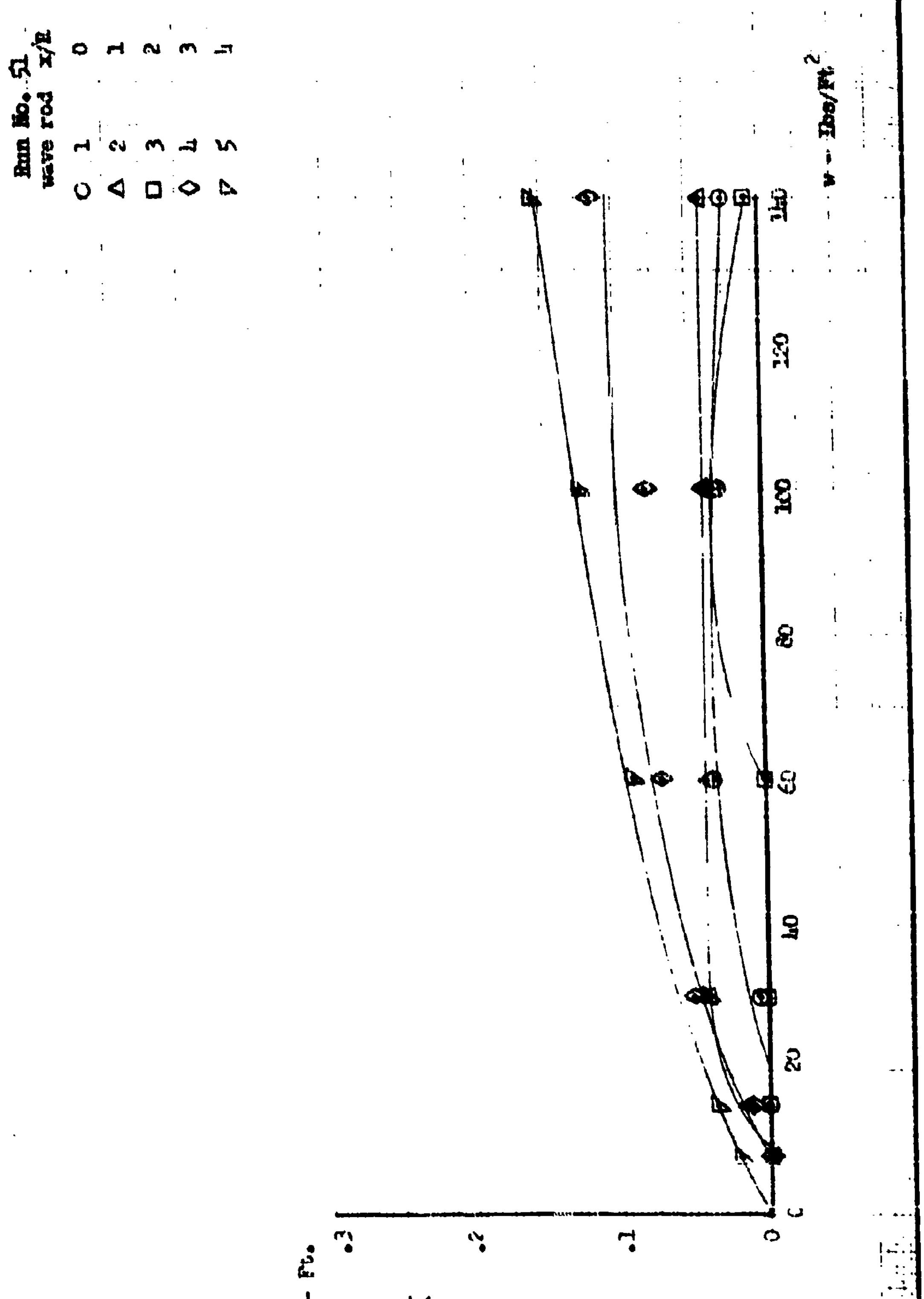

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FIGURE 145 WAVE FREQUENCY

V-46

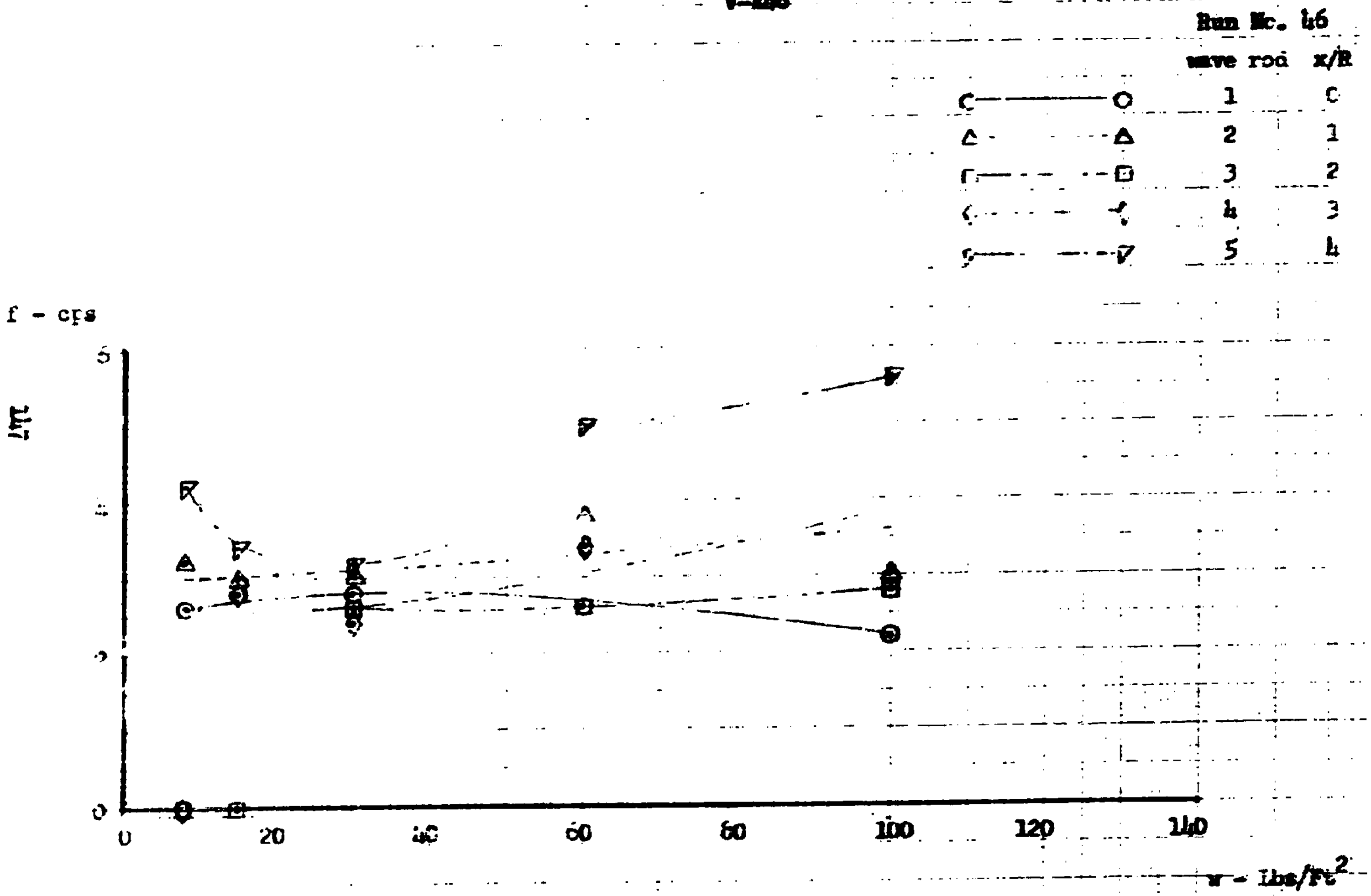

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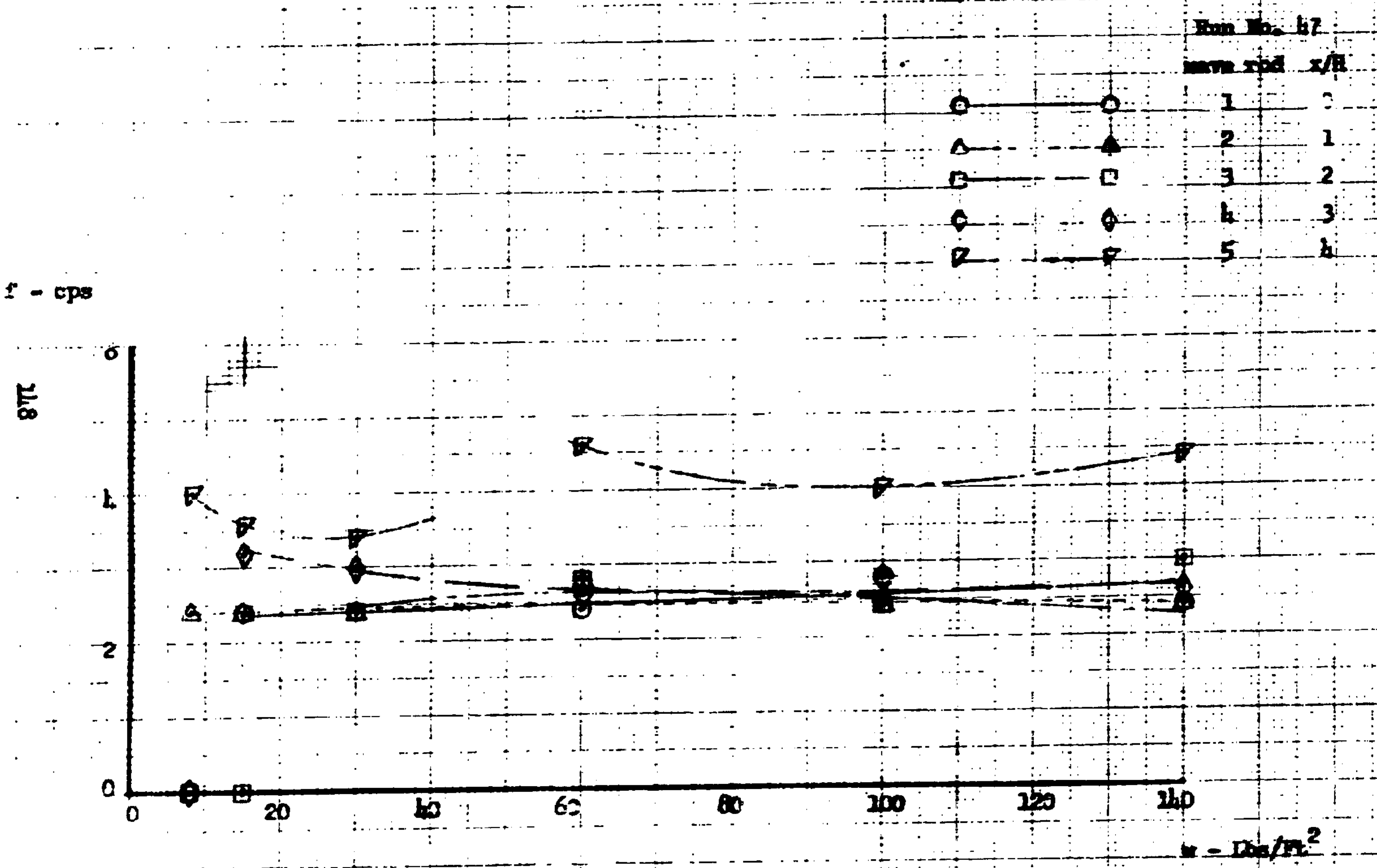
FIGURE 146 WAVE FREQUENCY

V-147



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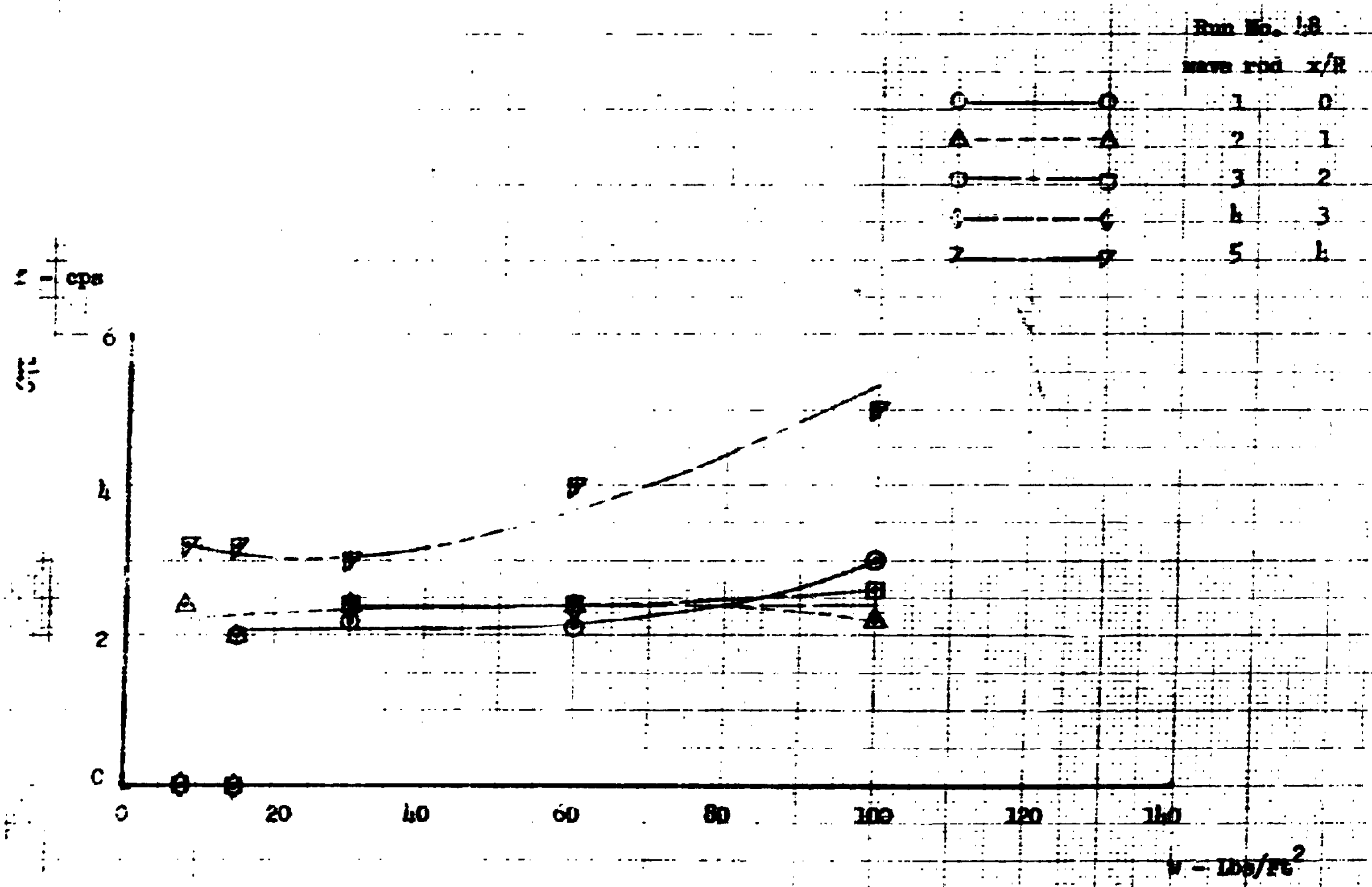
APPROVED				REPORT NO.

FIGURE 147 WAVE FREQUENCY

V-48



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APPROVED				REPORT NO.

FIGURE 148 WAVE FREQUENCY

V-450

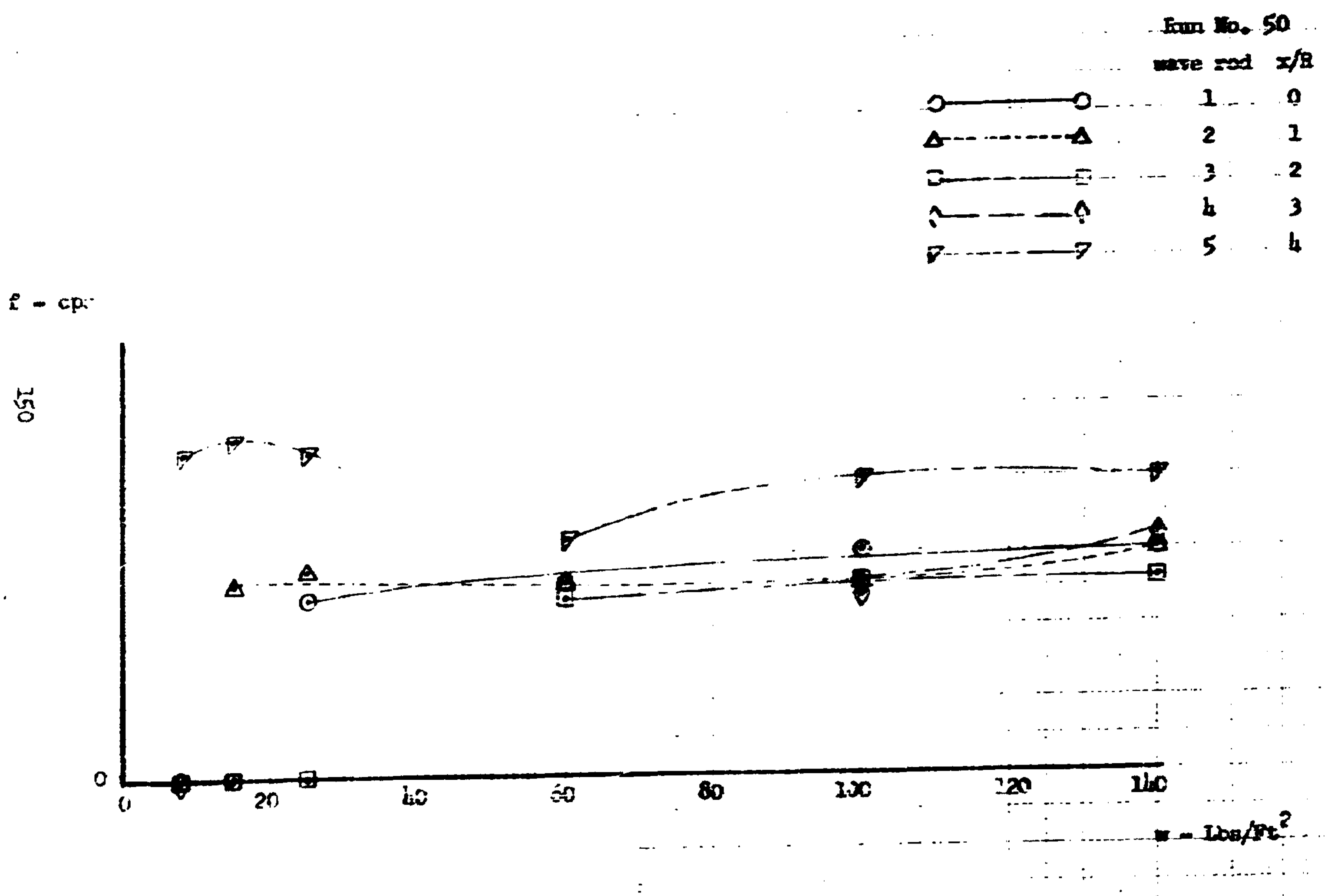

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FIGURE 145 WAVE FREQUENCY

V-49

Run No. 49		
	wave rod	x/R
○——○	1	0
△- - -△	2	1
□——□	3	2
◇——◇	4	3
▽-·-▽	5	4

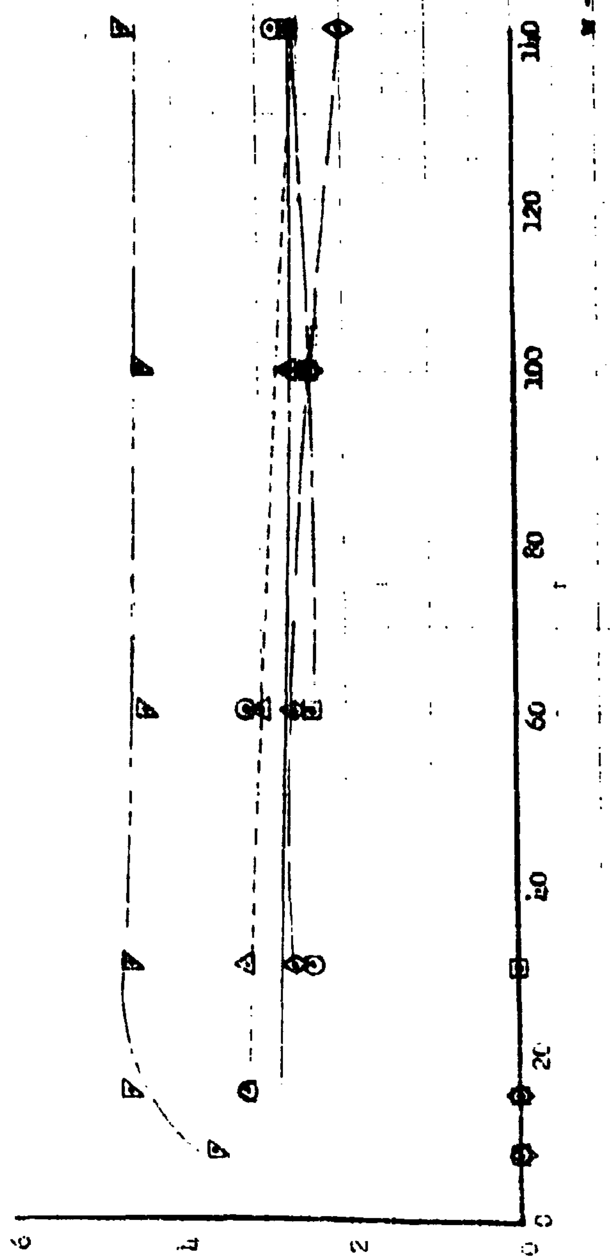

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FIGURE 150 WAVE FREQUENCY

V-A 51

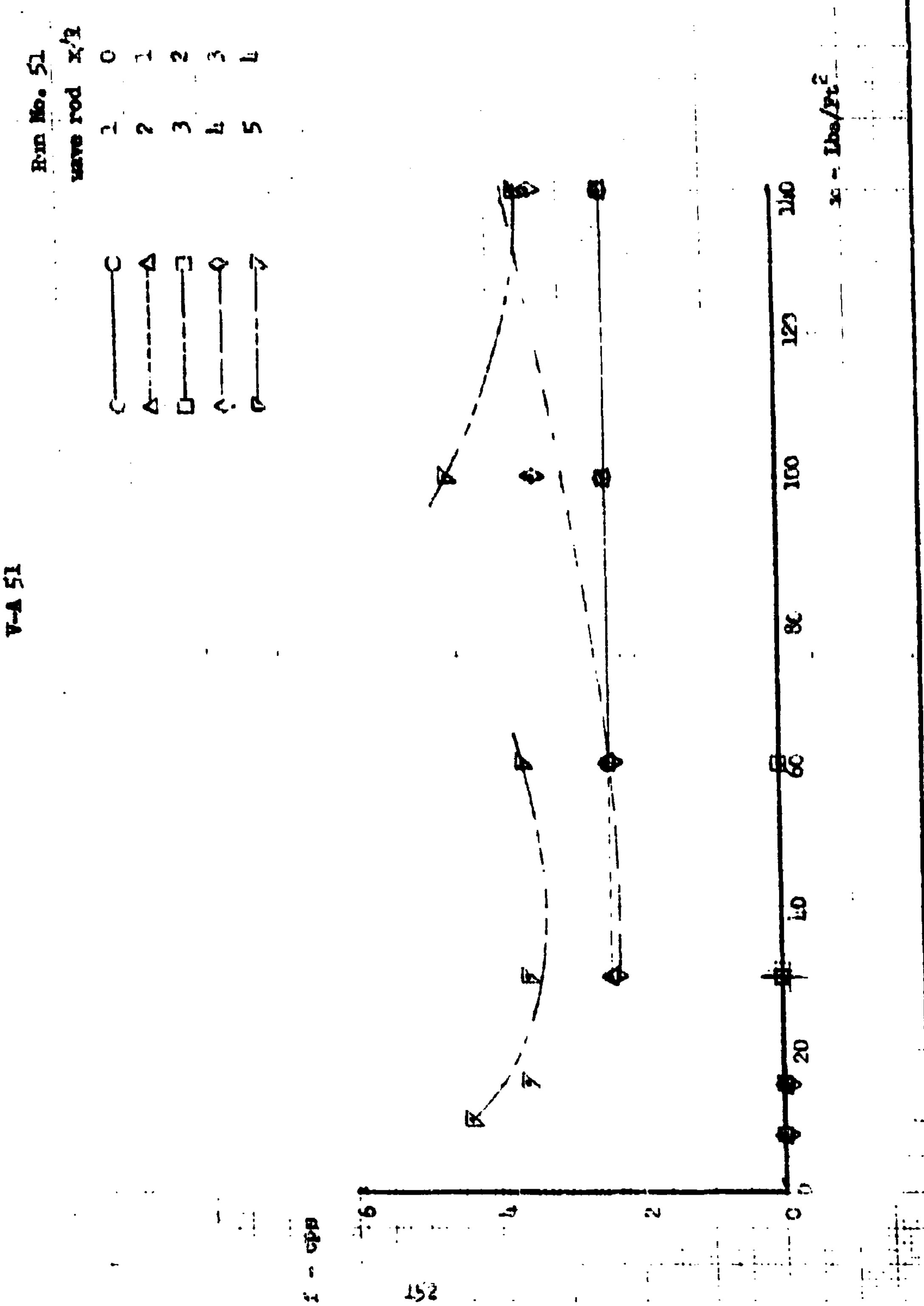
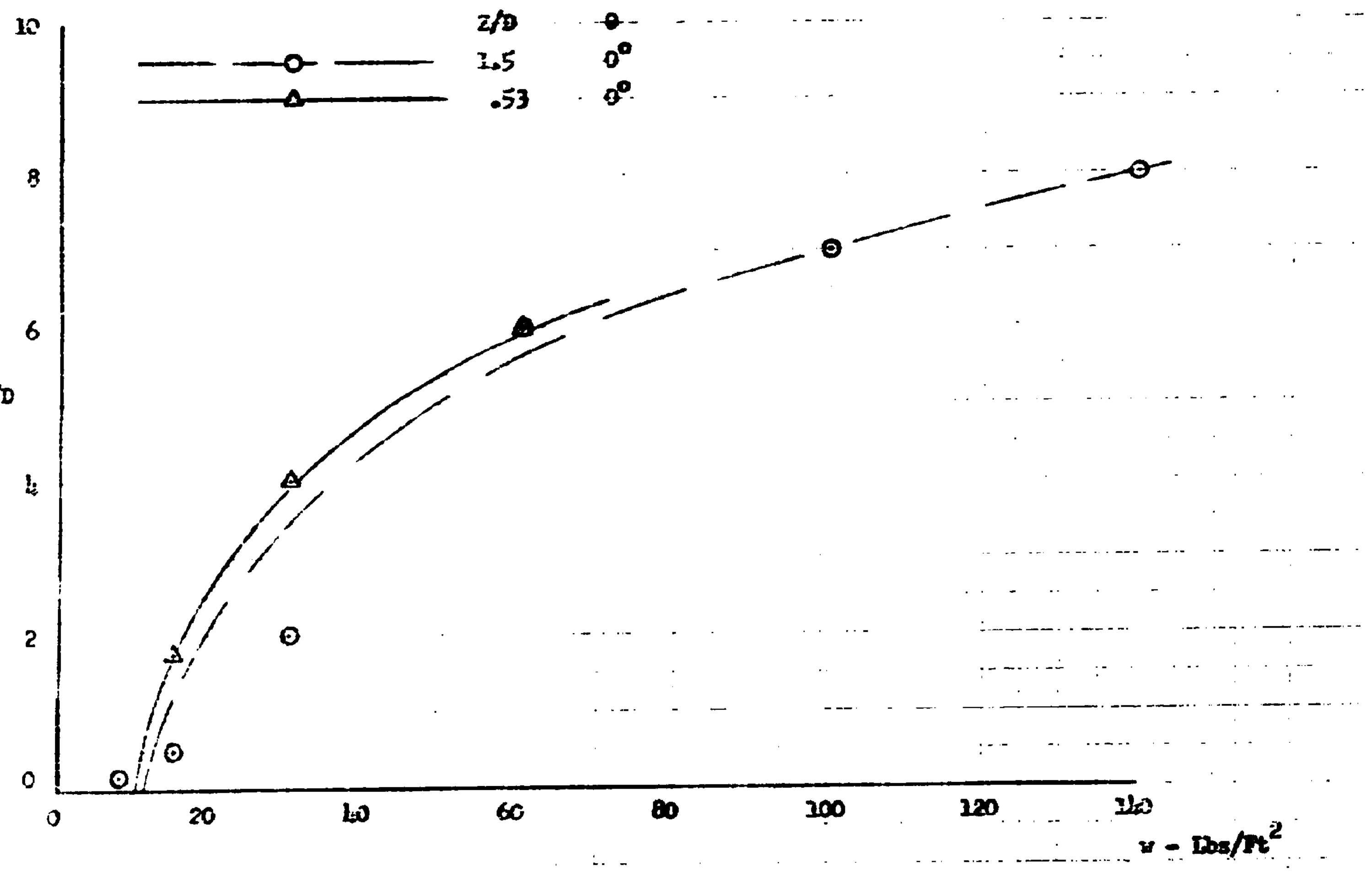


FIGURE 151 SPRAY HEIGHT, $\theta = 0^\circ$

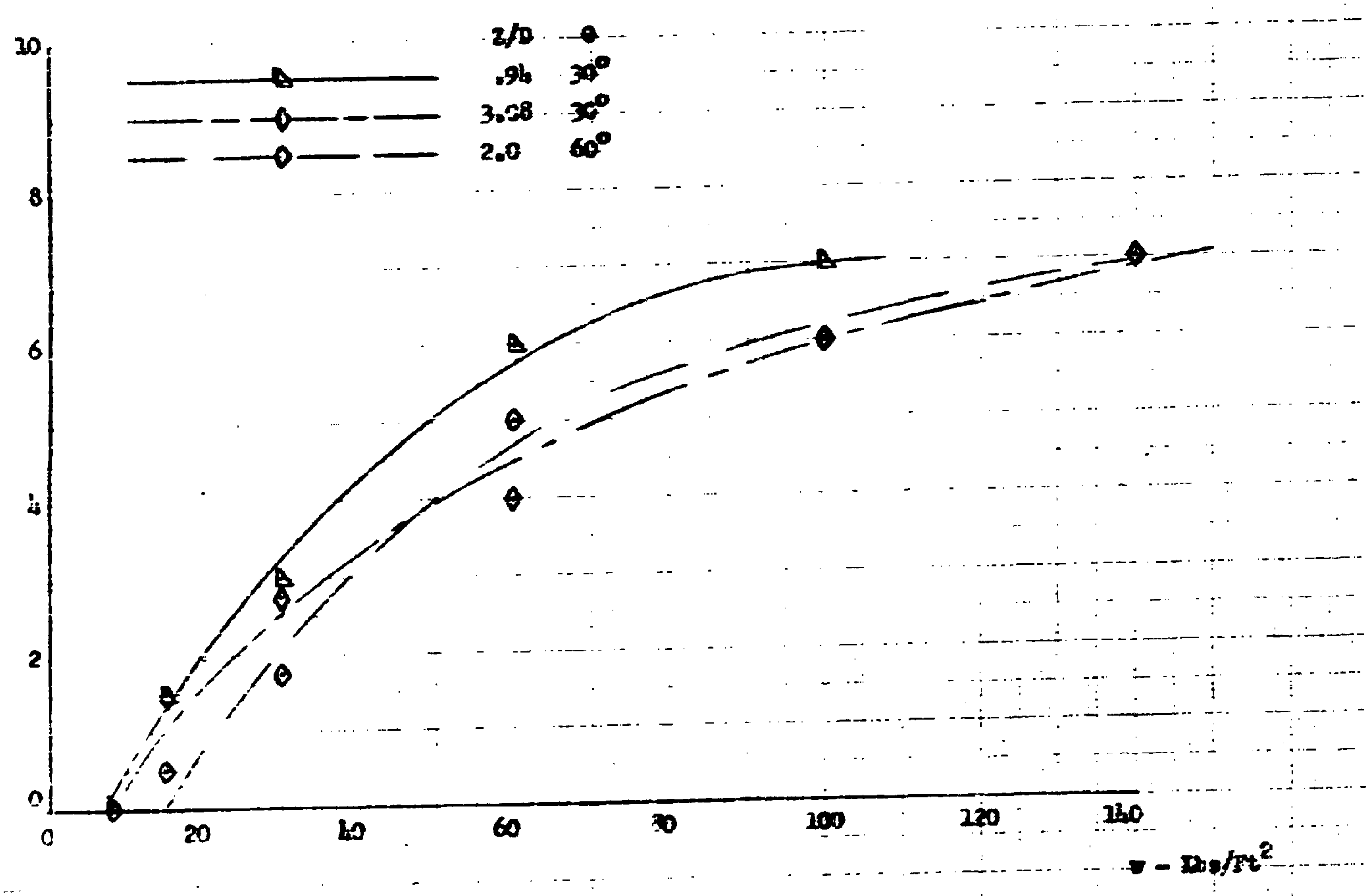
V-A



E-19D

FIGURE 152 SPRAY HEIGHT θ = 30° AND θ = 60°

V-A



APPENDIX I

DESCRIPTION OF SOILS AND TEST SITES

Introduction

1. The Hiller Aircraft Corporation has completed a part of the downwash impingement tests being conducted at the U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi. This testing includes 137 tests conducted with a two-foot ducted fan during the period 24 May to 1 July 1960. The Waterways Experiment Station supported the testing by furnishing the test sites and performing necessary soils tests for classification of the soils and for determination of the condition of the soils at the time of tests. This report presents a description of the test sites, classification of materials tested, and condition of materials at time of testing.

Terminology

2. Pertinent terms used in this report are defined as follows:

a. Unified Soil Classification System. The Unified Soil Classification System, which has been adopted as standard by the Corps of Engineers and the Bureau of Reclamation and is in general use by several other agencies, is used as a basis for classification of the soils tested. This system is based on the identification of soils according to their textural and plastic qualities and on their grouping with respect to behavior. The soil is given a descriptive name and a letter symbol indicating its principal characteristics. The following properties are used as a basis for classification:

(1) Percentage of gravel, sand, and fines (fraction passing No. 200 sieve).

(2) Shape of grain-size distribution curve.

(3) Plasticity and compressibility characteristics.

A complete description of the Unified Soil Classification System is given in Waterways Experiment Station Technical Memorandum No. 3-357 dated March 1953.

b. Atterberg limits. The Atterberg limits are defined briefly as the water content of a soil at the transition points between the general stages of consistency; that is, liquid, plastic, semisolid, and solid stages. The liquid limit (LL) and the plastic limit (PL)

express the upper and lower limits, respectively, of the plastic range of a soil. The difference between these two limits expresses numerically the plasticity of a soil and is referred to as the plasticity index (PI). The test procedures used for determining the liquid and plastic limits were essentially the same as ASTM Designations D 423-39 and D 424-39, respectively.

c. Gradation. Soil gradation refers to the distribution of grain sizes in soils. This distribution is normally shown by a grain-size curve in which grain size in millimeters is plotted against percentage of fines by weight. Sieve analysis tests (ASTM C 136-46) were used for determining the grain-size distribution of soil particles coarser than a 200-mesh sieve (0.074 mm), and a hydrometer analysis (ASTM D 422-54T) was used for determining grain-size distribution for materials finer than a 200-mesh sieve.

d. Water content. Water content (w) is the ratio, expressed as a percentage, of the weight of water in a soil mass to the weight of the solid matter. Tests were conducted in accordance with ASTM D 698-58T.

e. Density. Density of a soil is the weight per unit volume; in this report it is expressed as dry density in pounds per cubic foot. Tests were conducted by the sand-density and drive-cylinder methods in accordance with Corps of Engineers' procedures.

Description of Soils and Test Sites

3. Tests were performed on the following soils and test sites:

a. Lean clay (CL)

(1) Bladed section
(2) Plowed section (flat)
(3) Plowed section (furrowed)
(4) Grassy area (unmowed)
(5) Grassy area (freshly mowed)

b. Fat clay (CH)

c. Sand (SP)

(1) Dry
(2) Wet

d. Sandy gravel (GW)

e. Water

4. Grain-size distribution curves and Atterberg limits data for the soils tested are shown on plate 1. A narrative description of the soils and condition of test sites is presented in the following paragraphs.

5. Lean clay. The material used was a fine-grained soil of medium plasticity (PI of 13) which classified as a lean clay (CL). This soil is commonly referred to as a loess deposit and is typical of loess formations found throughout the midwestern part of the United States and many other areas of the world such as the southern edge of the Gobi Desert in central Asia, the Yellow Earth Area in northwestern China, central Europe, Palestine, and the western half of the Union of South Africa. Tests were conducted on the loess soil under the following conditions:

a. Bladed section. Tests 1 through 5 were conducted in an area 25 feet wide by 100 feet long after it had been bladed smooth with a motor patrol. The water content of the surface was about 17 percent immediately after the grading, and the dry density varied from about 93 to 108 pounds per cubic foot. This area would represent any bare area of similar soil, such as dirt roads, unsurfaced parking areas, etcetera, for a medium range of water content and density. Some drying of the exposed surface soil occurred during elapsed time between tests; this resulted in the formation of a crust about 1/2 to 3/4 inch thick. The surface was crazed and contained numerous shrinkage cracks prior to tests 2 through 5, as shown on photograph 1. Water content and density values of the soil measured at the time of tests are shown in table 1.

b. Plowed section (flat). Tests 6 through 30 were conducted in a flat plowed section approximately 20 by 250 feet in area. The material was scarified by one pass of the scarifying teeth on a motor patrol and then pulverized to a depth of about 9 inches with two passes of a pulvimixer. This resulted in a very loose material simulating a freshly plowed flat field which might be used for sowing grain crops such as wheat, oats, etcetera. The area contained material ranging in size from 3-inch clods of soil to dust. The dry density ranged from 60 to 77 pounds per cubic foot, and the water content ranged from 5 to 16 percent. Photograph 2 shows a general view of the area prior to testing. Actual test values of water content and density are given in table 1.

c. Plowed section (furrowed). Tests 31 through 39 were conducted in a plowed, furrowed area. This area was initially prepared in the same manner as the flat area described in b above, and then rows were formed with a middle-buster plow. The rows were spaced approximately three feet apart, with the top of the row about 9 inches above the

bottom of the furrow. This area would represent a freshly plowed field where furrows are usually formed for row crops such as corn, cotton, sugar cane, etcetera. The water content and density ranges were about the same as those for the flat plowed area. Actual values are shown in table 1.

d. Grassy area (unmowed). Tests 64 through 73 were conducted on an unmowed grassy area of lean clay soil. The grass consisted of a fairly dense covering of Johnson grass 2 to 2-1/2 feet high with some Bermuda grass and clover. The root system formed a moderately dense mat in the upper 1 to 1-1/2 inches of the soil. This area was cultivated for vegetable gardens during World War II but has been lying idle since about 1946. The area is typical of land which has been taken out of cultivation and permitted to grow up in grass and weeds for a period of several years.

e. Grassy area (mowed). Tests 53, 54, and 74 through 88 were conducted on a freshly mowed portion of the grassy area described above. The grass was mowed with a rotary-type power lawn mower but was not raked.

6. Fat clay. The material used for this portion of the testing was a fine-grained soil of high plasticity (PI of 47) which classified as a fat clay (CH) soil. The material was obtained from a backswamp deposit of the Mississippi River and is typical of heavy clays found throughout the world along well-developed flood plains with backswamps. The area used for tests was a stockpile of this material located on the Waterways Experiment Station reservation; it had been exposed to the weather for about one year. The upper 2 inches of the clay had dried to a water content of about 8 percent and contained numerous shrinkage cracks. The water content below the two-inch depth was about 31 percent. The dry density averaged about 88 pounds per cubic foot, which is about the average density of the natural material in the swamps. Tests 89 through 92 were made on the soil in this condition. Test 93 was conducted on the same soil after the dry surface material had been scraped off. Actual water content and density values are given in table 1.

7. Sand. The sand used in the tests classified as a nonplastic, uniform, fine sand (SP) and was obtained from a sand bar along a small river in the Vicksburg area. This sand is typical of many river bar sands found throughout the world, and the behavior under blast would be about the same for any sand of similar gradation, density, and water content. Tests were conducted on sand sections constructed under shelter for the following conditions:

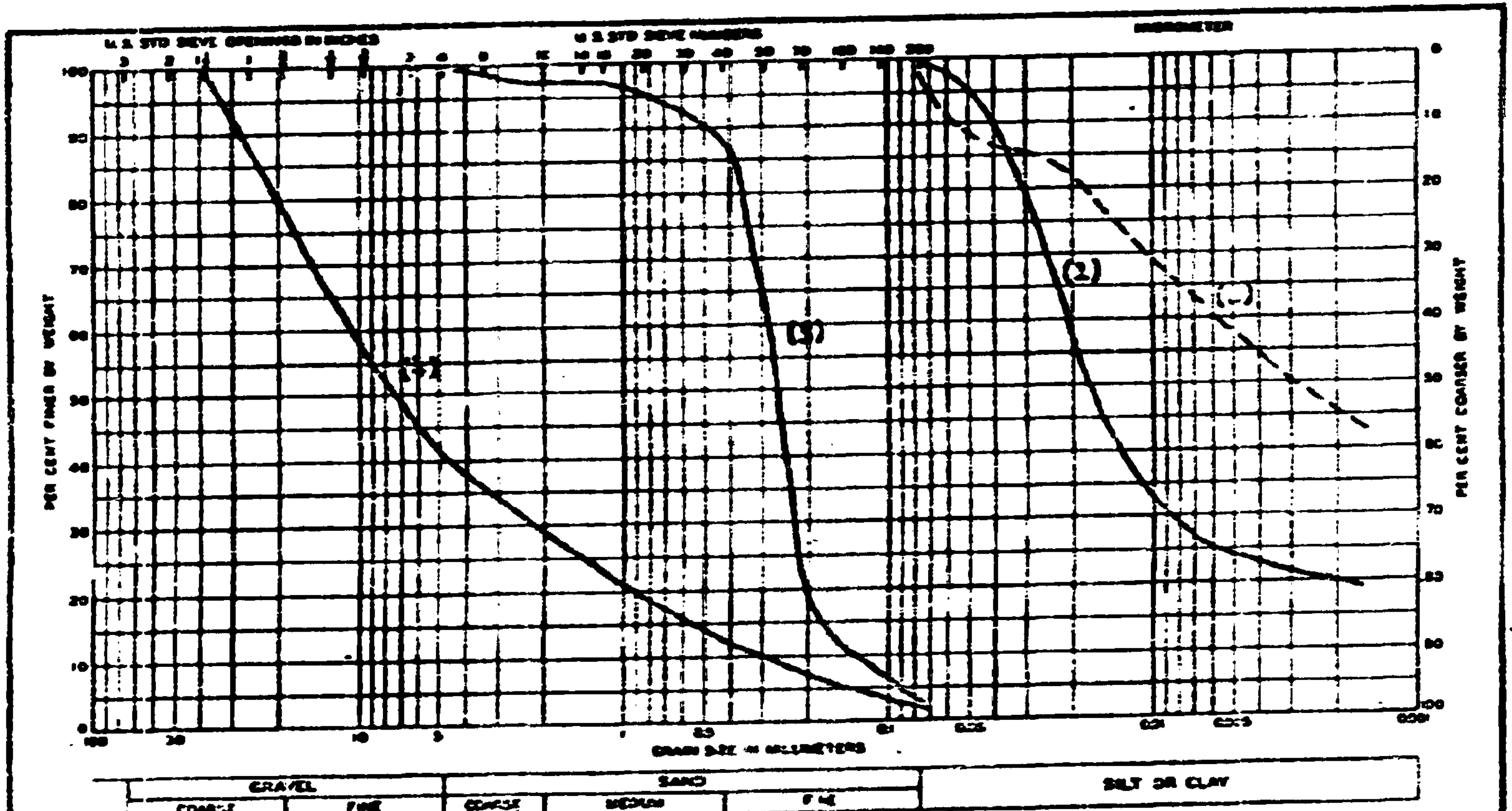
a. Dry sand. Tests 44, 45 and 94 through 120 were conducted on test sections which were 20 feet wide, 50 feet long, and 1 foot deep and were constructed of air-dry sand. The material was placed in a trench section and was hand-spread to grade. Water content values varied from about 0.5 percent at the surface to 1.7 percent at the bottom of the layer. The sand was in a relatively loose state and had an average dry density of about 92 pounds per cubic foot.

b. Wet sand. Tests 42 and 43 were conducted on wet sand. For these tests, a trench section 20 feet wide, 50 feet long, and 1 foot deep, well filled and leveled with sand in the same manner as the dry sand section, was used. The sand was then wet by sprinkling with a water hose and spray nozzle. The average water content and dry density of the sand at time of testing were 8.7 percent and 92.3 pounds per cubic foot, respectively.

8. Sandy gravel. The material used in these tests was nonplastic, well-graded sandy gravel (GW) with 1-1/2 inch maximum size particles. The material was obtained from an alluvial gravel bar deposit which is typical of such deposits along many streams throughout the world. The sandy gravel was placed in a trench section 20 feet wide, 60 feet long, and 1 foot deep with only a very slight compaction effort being applied. The material was sprinkled when placed and this resulted in a moist condition. Tests 40, 41, 55 through 63, and 121 through 137 were conducted in this section. After each series of tests, the eroded areas were repaired and the same section was used for additional tests. The water content of the material for tests 40, 41, 55 through 63, and 121 through 126 varied from about 0.3 percent at the surface to 3.0 percent at the bottom of the layer. The average dry density of the material was about 115 pounds per cubic foot, which is about the same degree of density found in natural deposits of the material. The entire area was sprinkled and compacted by four coverages of a D7 tractor prior to tests 127 through 137. This resulted in slightly higher water contents and densities of the material in these latter tests, as shown in table 1.

9. Water. Tests 46 through 52 were performed over water which was 22 inches deep and was confined by sand dikes to a pool approximately 40 feet wide by 100 feet long. The dikes were sloped to approximately 1 on 3 to dissipate any wave action occurring during the tests. Data for developing a profile of the trough produced under the various tests were obtained by instrumenting the area under the ducted fan with a series of wave rods and recording the water elevation on an oscillograph.

Plate 1
Table 1
Photographs 1-2



NUMBER	DEPTH	NATURAL MOISTURE	LL	PL	PI	CLASSIFICATION
(1)			38	25	13	Lean clay (CL)
(2)			70	23	47	Fat clay (CH)
(3)			Nonplastic			Uniform fine sand (SP)
(4)			Nonplastic			Sandy gravel (GW)

CLASSIFICATION DATA FOR SOILS USED IN DOWNWASH EXPERIMENT STUDY

TABLE 1

SUMMARY OF SOIL TESTS FOR DOWNWASH IMPINGEMENT STUDY

Test No.	Soil Type and Condition	Soil Conditions: Depth in.	Moisture Content %	Dry Density lb/cu ft
1	Lean clay (bladed)	0-1/2	17.3	
		1/2-3	21.3	95.8
2	"	0-1/2	8.5	
		1/2-3	17.2	99.9
3	"	0-1/2	9.7	
		1/2-3	19.4	97.3
4	"	0-1/2	5.2	
		1/2-3	15.4	104.7
5	"	0-1/2	5.0	
		1/2-3	15.6	96.2
6	Lean clay (plowed)	0-1	[illegible]	
		1-4	7.1	72.8
7	"	0-1	9.8	64.7
		1-2	13.4	
		2-4	12.9	
8	"	0-1	10.2	65.8
		1-2	14.2	
		4-6	12.3	
9	"	0-1	6.0	68.2
		1-2	12.7	
		2-6	13.7	
		7-10	17.9	93.3
10	"	0-1	14.6	65.2
		1-2	8.7	
		7-11	20.8	94.7
11	"	0-1	6.2	67.3
		1-2	13.5	

Test No.	Soil Type and Condition	Soil Conditions		
		Depth in.	Moisture Content %	Dry Density lb/cu ft
12	Lean clay (plowed)	0-1	7.5	67.2
		1-2	14.2	
		2-4	17.2	
13	"	0-1	10.8	63.7
		1-2	17.2	
		2-6	14.9	
		6-8	17.2	
14	"	0-1	6.7	66.8
		1-2	16.3	
		7-10	22.2	97.8
15	"	0-1	11.4	64.2
		1-2	18.2	
		6-10	22.4	94.6
16	"	0-1	15.4	62.8
		1-2	14.0	
17	"	0-1	15.3	64.6
		1-2	16.9	
		4-6	16.3	64.9
18	"	0-1	13.0	67.4
		1-2	15.2	
		4-6	13.0	67.3
		9-11	24.9	82.2
19	"	0-3	13.2	64.7
		8-11	17.7	91.5
20	"	0-3	10.0	65.2
		8-11	20.0	93.4
21	"	0-3	9.9	67.0
22	"	0-3	10.9	68.0
		4-7	11.0	
23	"	0-3	13.0	67.0
23'	"	3-6	17.0	
		6-9	19.9	69.2

Test No.	Soil Type and Condition	Soil Conditions: Depth in.	Soil Conditions: Moisture Content %	Soil Conditions: Dry Density lb/cu ft
24	Lean clay (plowed)	0-3	16.0	70.7
		4-7	20.0	69.0
		8-11	22.0	90.3
25	"	0-3	12.2	68.6
		9-11	20.4	
		11-14	23.5	93.3
26	"	0-3	12.9	67.5
		3-6	17.6	
		8-11	22.2	92.0
27	"	0-3	6.7	74.4
		3-8	18.6	
		8-11	22.8	95.9
28	"	0-3	11.6	71.4
		3-8	20.2	72.3
		10-13	21.4	90.8
29	"	0-3	17.0	68.7
		4-7	17.2	73.2
30	"	0-3	9.8	70.2
		3-8	18.6	76.5
		8-11	21.4	71.1
31	Lean clay (plowed and furrowed)	0-3	10.8	72.2
		9-12	12.3	94.5
32	"	0-3	13.5	71.6
		3-12	11.2	70.4
33	"	0-3	10.2	67.8
		3-7	11.6	76.1
		10-13	19.4	70.0
34	"	0-3	12.2	[illegible].0
35	"	0-3	9.3	73.8
		4-7	12.0	71.[illegible]

Test No.	Soil Type and Condition	Soil Conditions		
		Depth in.	Moisture Content %	Dry Density lb/cu ft
36	Lean clay (plowed and furrowed)	0-3 7-10 12-15	12.3 17.0 17.8	66.4 69.6 86.4
37	"	0-3 3-13	22.8 14.2	73.1 81.4
38	"	0-3 8-11 11-13	18.0 14.5 17.5	67.0 81.1 81.2
39	"	0-3 7-10 13-16	19.4 17.3 21.0	69.4 74.4 84.0
40-41	Sandy gravel	0-2 2-6 6-9 9-12	0.3 0.8 1.5 2.9	115.0
42-43	Sand (wet)	0-12	8.7	92.3
44-45	Sand (dry)	0-9 9-12	0.5 1.3	92.2
46-54	Water	-	-	-
55-63	Sandy gravel	0-2 2-6 6-9 9-12	0.3 0.8 1.5 2.9	115.0
64-88	Lean clay, grassy area (mowed and unmowed)	-	-	-
89	Fat clay (weathered)	0-2 2-6	8.1 33.1	87.1
90	"	0-2 2-6	8.0 22.6	86.5

Test No.	Soil Type and Condition	Soil Conditions: Depth in.	Soil Conditions: Moisture Content %	Soil Conditions: Dry Density lb/cu ft
91	Fat clay (weathered)	0-2	8.5	
		2-6	37.0	81.0
92	"	0-2	8.[illegible]	
		2-6	34.6	81.9
93	Fat clay (bladed)	0-6	36.1	82.1
94-120	Sand (dry)	0-9	0.5	92.2
		9-12	1.3	
121-126	Sandy gravel	0-2	0.3	115.0
		2-6	0.8	
		6-9	1.8	
		9-12	3.0	
127-137	"	0-2	3.2	118.0
		2-6	4.3	
		6-9	3.7	
		9-12	3.7	

APPENDIX II

TABLE I

Soil Designation	Z/D	W	θ	Test Time	Remarks
I-A1	1.5	140	0°	variable	
I-A2	3	125	0°	2 min.	
I-A3	1.5	var.	0°	variable	
I-A4	.5	var.	0°	variable	
I-A5	.6	var.	30°	variable	
I-B6	3	6.8	0°	3 min.	
I-B7	3	20.1	0°	3 min.	
I-B8	3	45.2	0°	3 min.	
I-B9	3	84.6	0°	3 min.	
I-B10	3	125	0°	3 min.	
I-B11	1.5	6.8	0°	3 min.	
I-B12	1.5	20.1	0°	3 min.	
I-B13	1.5	45.2	0°	2 min.	
I-B14	1.5	84.6	0°	42 sec.	
I-B15	1.5	125	0°	40 sec.	
I-B16	.5	6.8	0°	2 min.	
I-B17	.5	20.8	0°	2 min.	
I-B18	.5	49.8	0°	2 min.	
I-B19	.5	95	0°	1 min.	
I-B20	.5	137.5	0°	40 sec.	
I-B21	3	15	30°	3 min.	
I-B22	3	30	30°	3 min.	
I-B23	3	60	30°	1 min.38 sec.	After 1/2 hour test rerun over original location.
I-B24	3	60	30°	1 min.38 sec.	Sprinkled.
I-B25	3	60	30°	1 min.38 sec.	
I-B26	3	127	30°	45 sec.	
I-B27	.75	60	30°	1 min.	
I-B28	.75	127	30°	1 min.	
I-B29	2	60	60°	1 min.	
I-B30	2	133	60°	1 min.	
I-C31	3	15	0°	1 min.	
I-C32	3	60	0°	1 min.	
I-C33	3	135	0°	1 min.	
I-C34	.83	var.	0°	-	
I-C35	.83	30	0°	1 min.	
I-C36	.83	100	0°	1 min.	
I-C37	.83	var.	0°	-	Sprinkled surface.
I-C38	.83	30	0°	1 min.	Sprinkled surface.
I-C39	.83	100	0°	1 min.	
I-D53	2.21	140	0°	1 min.	
I-D54	1	100	0°	1 min.	

Soil Designation	Z/D	W	θ	Test Time	Remarks
I-D64	3	125	0°	4 min.	
I-D65	3	15	0°	1 min.	
I-D66	3	30	0°	1 min.	
I-D67	3	60	0°	1 min.	
I-D68	1.5	15	0°	1 min.	
I-D69	1.5	30	0°	1 min.	
I-D70	1.5	145	0°	4 min.	
I-D71	.5	15	0°	1 min.	
I-D72	.5	30	0°	1 min.	
I-D73	.5	100	0°	4 min.	
I-E74	3	15	0°	1 min.	
I-E75	3	30	0°	1 min.	
I-E76	3	60	0°	1 min.	
I-E77	3	100	0°	1 min.	
I-E78	3	140	0°	4 min.	
I-E79	1.5	15	0°	1 min.	
I-E80	1.5	30	0°	1 min.	
I-E81	1.5	60	0°	1 min.	
I-E82	1.5	100	0°	1 min.	
I-E83	1.5	135	0°	4 min.	
I-E84	.5	15	0°	1 min.	
I-E85	.5	30	0°	1 min.	
I-E86	.5	100	0°	4 min.	
I-E87	1	100	30°	1 min.	
I-E88	2	133	60°	45 sec.	
II-A89	1.5	var.	0°	-	
II-A90	3	var.	0°	-	
II-A91	.5	var.	0°	-	
II-A92	.96	var.	30°	-	
II-B93	.5	var.	0°	-	
III-A44	3	var.	0°	1 min.	
III-A45	3	60	0°	1 min.	
III-A94	3	8	0°	1 min.	
III-A95	3	15	0°	1 min.	
III-A96	3	30	0°	1 min.	
III-A97	3	60	0°	1 min.	
III-A98	3	100	0°	1 min.	
III-A99	1.5	8	0°	1 min.	
III-A100	1.5	15	0°	1 min.	
III-A101	1.5	30	0°	1 min.	
III-A102	1.5	100	0°	1 min.	
III-A103	.5	8	0°	1 min.	
III-A104	.5	15	0°	1 min.	
III-A106	.5	30	0°	1 min.	
III-A107	.5	60	0°	1 min.	

Soil Designation	Z/D	w	θ	Test Time	Remarks
III-A108	.5	100	0°	1 min.	
III-A109	.75	60	30°	1 min.	
III-A110	.75	30	30°	1 min.	
III-A111	.75	15	30°	1 min.	
III-A112	.75	8	30°	1 min.	
III-A113	3	8	30°	1 min.	
III-A114	3	15	30°	1 min.	
III-A115	3	30	30°	1 min.	
III-A116	3	60	30°	1 min.	
III-A117	2	8	60°	1 min.	
III-A118	2	15	60°	1 min.	
III-A119	2	30	60°	1 min.	
III-A120	2	60	60°	1 min.	
III-B42	1.5	var.	0°	-	
III-B43	.667	125	0°	1 min.	
IV-A40	1.5	var.	0°	1 min.	
IV-A41	1.5	60	0°	1 min.	
IV-A55	3	15	0°	1 min.	
IV-A56	3	30	0°	1 min.	
IV-A57	3	60	0°	1 min.	
IV-A58	3	100	0°	1 min.	
IV-A59	3	133	0°	1 min.	
IV-A60	1.5	15	0°	1 min.	
IV-A61	1.5	30	0°	1 min.	
IV-A62	1.5	100	0°	1 min.	
IV-A63	1.5	140	0°	1 min.	
IV-A121	2	15	60°	30 sec.	Bearing failure during test.
IV-A122	.5	15	0°	1 min.	
IV-A123	.5	30	0°	1 min.	
IV-A124	.5	60	0°	15 sec.	
IV-A125	.75	30	30°	1 min.	
IV-A126	.75	60	30°	20 sec.	
IV-B127	1.5	15	0°	1 min.	
IV-B128	1.5	30	0°	1 min.	
IV-B129	1.5	60	0°	1 min.	
IV-B130	1.5	100	0°	30 sec.	
IV-B131	.5	15	0°	1 min.	
IV-B132	.5	30	0°	1 min.	
IV-B133	.5	60	0°	1 min.	
IV-B134	.5	100	0°	30 sec.	
IV-B135	3	30	0°	1 min.	
IV-B136	3	60	0°	1 min.	
IV-B137	3	100	0°	1 min.	

Soil Designation	Z/D	W	θ	Test Time
V-A46	3	*	0°	-
V-A47	1.5	**	0°	-
V-A48	.53	*	0°	-
V-A49	.937	**	30°	-
V-A50	3.08	**	30°	-
V-A51	2.0	**	60°	-
V-A52	3.03	*	60°	-

* 0, 15, 30, 60, 100

** 0, 15, 30, 60, 100, 140